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①

Introduction

- 1) Dc circuits
- 2) Theorem
- 3) Ac circuits 1- ϕ
3- ϕ
- 4) Intro to electrical machines
principle

- Atom consists of 2 types of charges: positive & negative
- When we remove/add electrons to the atom, it becomes either positively charged or negatively charged
- Two oppositely charged bodies possess certain amount of pd because of separation b/w them
- This difference in potential energies of charges is called potential difference
- One volt is the potential difference b/w 2 points when one joule of energy is used to pass one coulomb of charge from one point to other
- When we apply electrical potential to any conducting material, the free electrons flow in an ordered fashion, this constitutes electric current

Electric currents

- It is defined as rate of flow of charge in conducting material passing through a point in unit time

$$I = \frac{Q}{t}$$

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- Measured in amperes

Electric power

product of electric potential & current gives power, which gives rate of change of electric energy per time

$$P = VI$$

$$= \frac{dw}{dq} \frac{dq}{dt}$$

$$= \frac{dw}{dt} = \frac{w}{t}$$

Electrical energy

$$W = VIt$$

Electrical elements

1) Resistance / Resistor

2) Induction / Inductor

3) Capacitance / Capacitor

4) Voltage source

5) Current source

Resistance:-

It is defined as property of an element due to which it opposes the flow of current through it.

Resistor = ohm

Symbol = Ω or $\sim$

Ohm's Law

$$V = IR$$

Resistor dissipates power or energy

Inductance (L)

property of an element by which it opposes the change in current

Unit :- Henry / H

Inductor made of copper or aluminium

Symbol $\rightarrow$ $\sim$

Inductance comes into picture when there is change in current.
Inductor stores energy in electromagnetic field $= \frac{1}{2} LI^2$

Capacitance (C)

Unit :- farads (F)

property of an element by which it opposes change in voltage

Capacitor stores energy in electrostatic potential

V-I relationship for capacitor $I = C \frac{dV}{dt}$

Voltage (V) :-

Ideal voltage source :- voltage is constant irrespective of current through it

practical voltage source :- As I increases, V decreases slowly.



ideal



practical

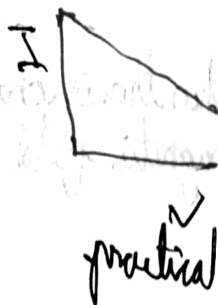
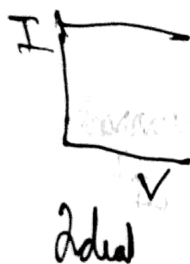
- There is no ideal voltage source in nature because everything has some internal resistance

Ideal current source

I is constant irrespective of the voltage

practical current source

As V decreases, I decreases



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Resistance:-

$$R \propto l$$

$$R \propto \frac{1}{a}$$

$$R \propto \frac{1}{a}$$

$$R = \rho \frac{l}{a}$$

Resistance also depends on temperature

Ohm's law:-

on a conductor

The potential difference b/w 2 points is directly proportional to the current flowing through it at constant temperature

$$V \propto I$$

$$\Rightarrow V = RI$$

$$\frac{V}{R} = I$$

$$\frac{V}{I} = R$$

Q) determine the voltage if 70J of energy is used to move the 30C of charge via conduction

$$W = 70J$$

$$Q = 30C$$

$$V = \frac{W}{Q} = \frac{70}{30} = 2.33V$$

- Q) SC of charge passed via given point in a conductor in 2 seconds. How many amps of current is flowing through the conductor

$$I = \frac{Q}{t}$$

$$= \frac{5}{2}$$

$$= 2.5A$$

- Q) The current in an inductor is changing at a rate of $2A/sec$. Find voltage across inductor and energy stored in the inductor

$$\mathcal{E} = L \frac{di}{dt}$$

$$= 2 \times 2$$

$$= 4V$$

Energy stored by inductor

$$E \text{ or } W = \frac{1}{2} Li^2$$

$$= \frac{1}{2} \times 2^2$$

$$= 2J$$

- Q) A 10Ω resistor is connected across $12V$ battery. How much current flows through the resistor. How much power is dissipated by the resistor

$$I = \frac{V}{R}$$

$$= \frac{12}{10} = 1.2 \text{ A}$$

$$P = VI$$

$$= 12 \times 1.2 = 14.4 \text{ W}$$

$$P = I^2 R$$

$$= 1.2^2 \times 10$$

$$= \frac{V^2}{R} = \frac{12^2}{10} = 14.4 \text{ W}$$

Q) The heater element of electric kettle has a constant resistance of 100Ω . Applied voltage is 250 V . The heater is used for 2 hours to heat the water. What is the current drawn by the heater and how much energy is consumed by the heater.

$$R = 100 \Omega$$

$$V = 250 \text{ V}$$

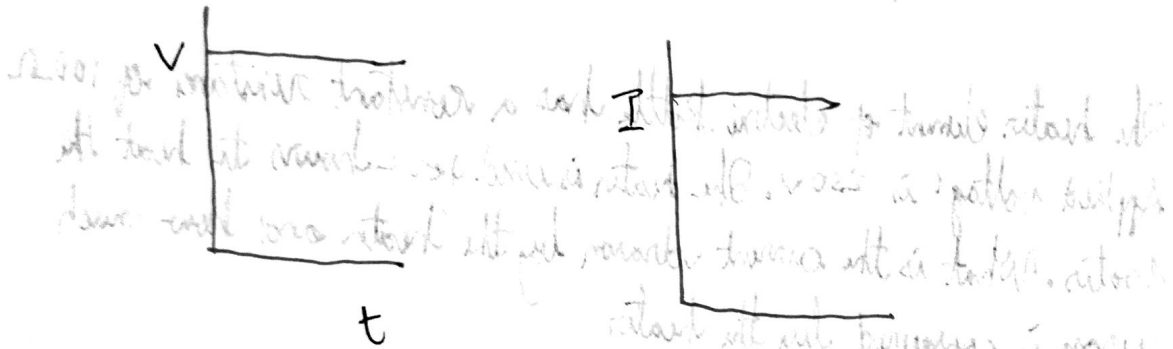
$$I = \frac{V}{R} = \frac{250}{100} = 2.5 \text{ A}$$

$$\begin{aligned} \text{Energy consumed} &= P \times t = I^2 R t \\ &= 2.5^2 \times 100 \times 2 \\ &= 1250 \text{ Wh} \\ &= 1.25 \text{ kWh} \end{aligned}$$

Electrical Network Terminology

Branch Electric elements having atleast one closed path

1) DC circuits



voltage & current are constant

It has resistance, current source, voltage source

Limitations of ohm

Limitations of ohm's law:-

- 1) applicable only for metallic devices

Nodes:-

point ~~connections~~ where 2 or more elements are connected to it

Junction

point ^{where} more than 2 elements are connected

Note:- All junctions are nodes but not all nodes are junctions

Branch:-

part ~~is~~ of network which lies between 2 nodes

Loop:-

A closed ^{path} in the circuit

Mesh:-

- Mesh is a closed path that doesn't contain other closed paths in it.
- It is the smallest loop

Kirchoff's circuit law:-

- algebraic sum of current entering the junction is equal to the current leaving the circuit
- in any electric circuit is zero
- Current entering junction is equal to current leaving the junction

Kirchoff's voltage law:-

In any electric network, the algebraic sum of voltages & products of resistances in any closed electric network + algebraic sum of EMF

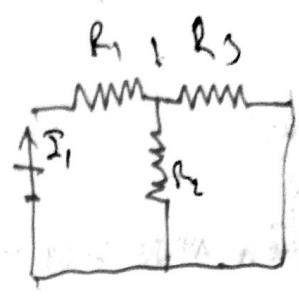
in that path is equal to zero

$$\sum IR + \sum \text{emf} = 0$$

voltage drop in $R_1 = I_1 R_1$

voltage drop in $R_2 = I_2 R_2$

voltage drop in $R_3 = I_3 R_3$



$$-I_1 R_1 - I_2 R_2 + V_S = 0$$

$$V_S = I_1 R_1 + I_2 R_2$$

Voltage sources in series

for more voltage, connect them in series

in parallel, voltage is same but current is more

Two resistors

Symbol $\rightarrow$

if we want more current then we have to connect in parallel

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Resistances connected in series

direction of current

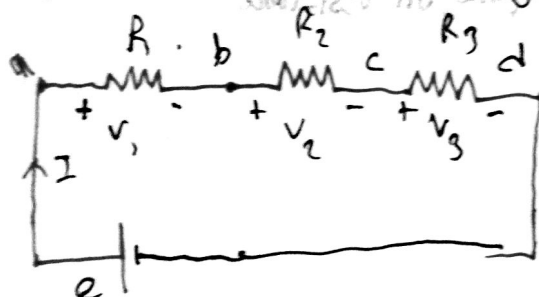
Unilateral $\rightarrow$ depends on polarity

bilateral $\rightarrow$ direction of current doesn't depend on polarity

Resistor is bilateral

Properties:

- Current is same in series
- Resistances are additive
- Voltage drops are additive
- Powers are additive
- Voltage drops across resistances every element will depend on resistance value



$V_1 \rightarrow$ Potential drop across $R_1 = IR_1$

$V_2 \rightarrow$ Potential drop across $R_2 = IR_2$

$V_3 \rightarrow$ Potential drop across $R_3 = IR_3$

According to KVL for loop abcde

$$+V - V_1 - V_2 - V_3 = 0$$

$$V = V_1 + V_2 + V_3$$

$$= IR_1 + IR_2 + IR_3$$

$$V = I(R_1 + R_2 + R_3)$$

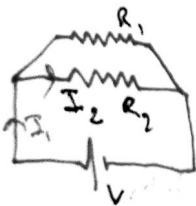
$$R_{eq} = \frac{V}{I} = R_1 + R_2 + R_3$$

Resistances connected in parallel

Properties

- Same voltage across elements
- Conductances are additive
- Currents are additive
- Powers are additive
- Current via each element depends on resistance

Special cases



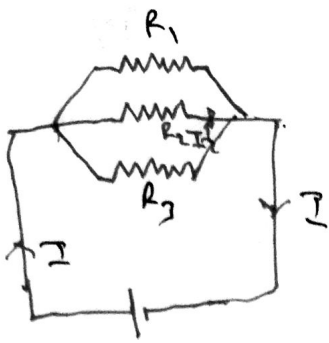
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R_{eq}} = \frac{R_1 + R_2}{R_1 R_2}$$

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

$$I_1 = I \left(\frac{R_2}{R_1 + R_2} \right)$$

$$I_2 = I \left(\frac{R_1}{R_1 + R_2} \right)$$



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as per KCL

$$I = I_1 + I_2 + I_3$$

$$= \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{I}{V} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right)$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Conductance

$$G_{eq} = G_1 + G_2 + G_3$$

$$\frac{3.7}{15\sqrt{50}} = \frac{45}{50}$$

find a) Current

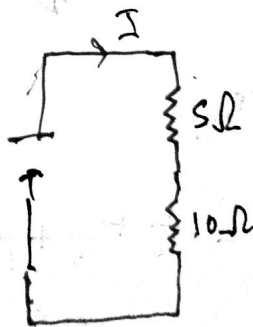
b) voltage across 5Ω & 10Ω so v

$$R_{eq} = R_1 + R_2 = 15\Omega$$

$$I = \frac{V}{R} = \frac{50}{15} = 3.33 \text{ A} \quad \text{--- (a)}$$

Voltage across 5Ω

$$V = IR = 3.33 \times 5 = 16.65 \text{ V}$$



voltage across 10Ω

$$V = IR$$

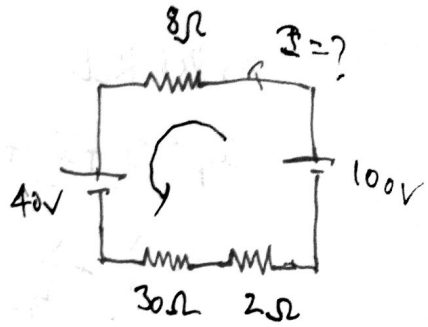
$$= \frac{10}{3} \times 10 = \frac{100}{3} \text{ V} \quad \text{--- (b)}$$

find current in the circuit

Given

$$V_1 = 100\text{V}, V_2 = 40\text{V}$$

$$R_1 = 30\Omega, R_2 = 2\Omega, R_3 = 8\Omega$$



Using KVL

$$+100 - 8i - 40 - 30i - 2i = 0$$

$$V_{\text{net}} = 100 - 40\text{V}$$

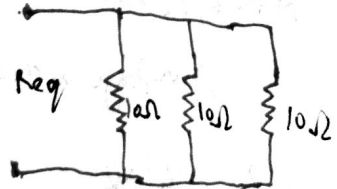
$$R_{\text{net}} = 40\Omega$$

$$I_{\text{net}} = \frac{60}{40} = 1.5\text{A}$$

find R_{eq}

$$\frac{1}{R_{\text{eq}}} = \frac{1}{10} + \frac{1}{10} + \frac{1}{10} = \frac{3}{10}$$

$$R_{\text{eq}} = \frac{10}{3} \Omega$$



If same n resistors are connected in parallel then we can use

$$R_{\text{eq}} = \frac{R}{n}, \text{ where } n \text{ is no of resistors}$$

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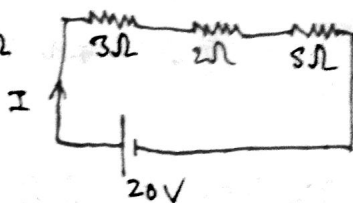
(14)

Voltage divider rule

$$V_1 : V_2 : V_3 = R_1 : R_2 : R_3$$

Only applicable in series circuit

- Q) Find the voltage across 3Ω , 5Ω , 2Ω without calculating current



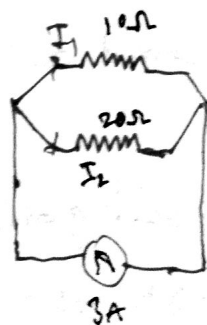
$$V_1 : V_2 : V_3 = R_1 : R_2 : R_3 \\ = 3 : 2 : 5$$

$$V_1 = V \times \frac{3}{3+2+5} \\ = 6V$$

$$V_2 = 20 \times \frac{2}{3+2+5} \\ = 20 \times \frac{2}{10} = 4V$$

$$V_3 = 20 \times \frac{5}{10} \\ = 10V$$

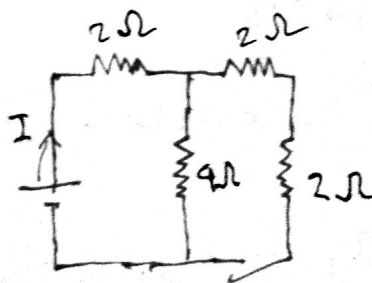
Q)



- Q) Find current from the battery

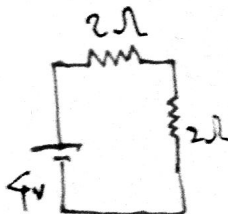
$$I = \frac{V}{R_{eq}}$$

2Ω & 2Ω are in series
So replaced by 4Ω



$$4 \parallel 4 = 2\Omega$$

$$I = \frac{4}{2+2} = 1A$$



Q) find current in 2Ω resistor

$$\frac{8.6}{3 \times 20} = \frac{19}{2}$$

A) R_1, R_2 are parallel

$$\Rightarrow \frac{1}{R_{12}} = \frac{1}{10} + \frac{1}{20}$$

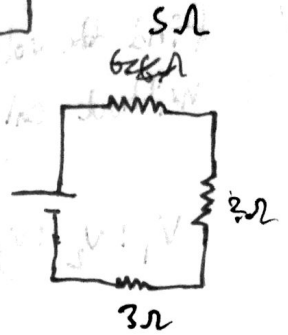
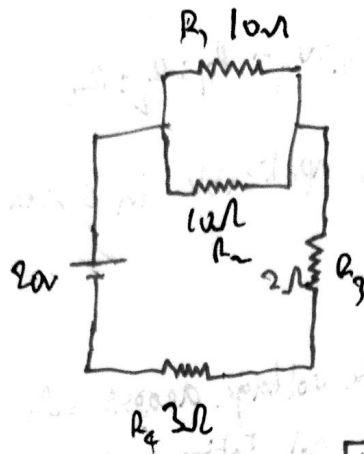
$$\frac{1}{R_{12}} = \frac{20+10}{10 \times 20} = \frac{30}{200}$$

$$R_{12} = \frac{200}{30} = 6.67 \Omega$$

$$R_{eq} = 5 + 2 + 3 = 10 \Omega$$

$$V = IR$$

$$I = \frac{V}{R} = \frac{9}{2+2} = 1A$$



Q) Find current delivered by the source & power dissipated by 28Ω

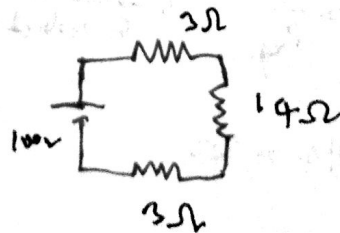
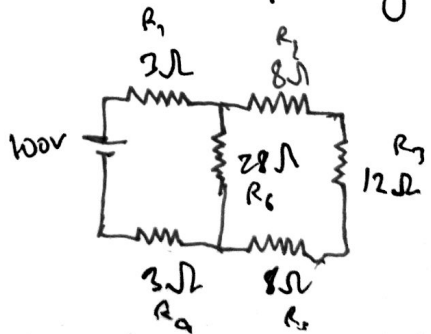
A) R_1 is getting divided into parallel

$$R_{123} = 8 + 12 + 8 = 28 \Omega$$

$$R_{123} = R_6$$

$$\Rightarrow 28 || 28 = 14 \Omega \text{ (since } R_{123} \text{ \& } R_6 \text{ are parallel)}$$

$$\begin{aligned} R_{eq} &= R_{123} + R_1 + R_4 \\ &= 14 + 3 + 3 \\ &= 20 \Omega \end{aligned}$$



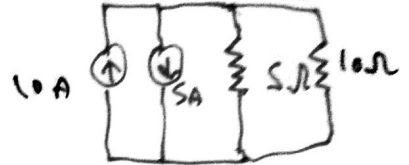
$$I = \frac{V}{R_{eq}} = \frac{100}{20} = 5A$$

$$P = I^2 R$$

$$= 2.5^2 \times 28$$

$$= 245W$$

Find the current

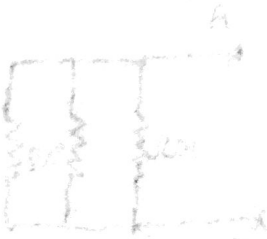


Since power source is in opp. direction

Resultant current $= 10A - 5A$
 $= 5A$

$$I_1 = I \frac{R_2}{R_1 + R_2}$$

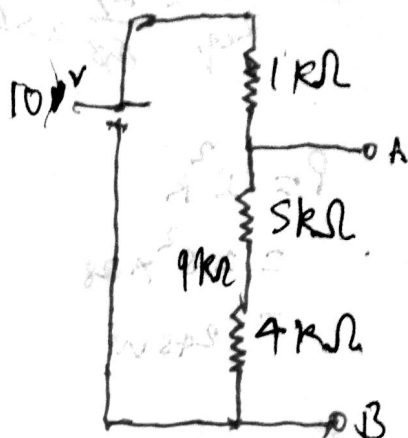
$$= 15 \times \frac{10}{5 + 10} = 10A$$



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Q) Find potential h/w A & B
~~V_A~~ As per voltage divider rule

$$V_{AB} = 9V$$

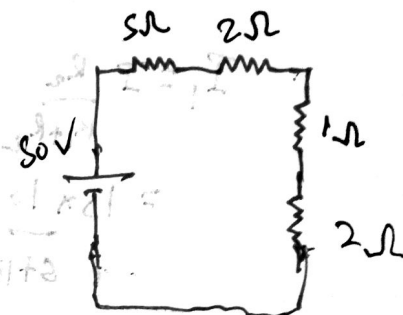


voltage divided in
 ratio 1:9

Q) Determine total amount of power dissipated in the circuit

$$P = \frac{V^2}{R}$$

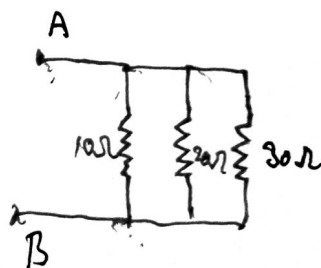
$$= \frac{50 \times 50}{1} = 250W$$



Q) Determine Req b/w terminals A & B

$$\frac{1}{R_{eq}} = \frac{1}{10} + \frac{1}{20} + \frac{1}{30}$$

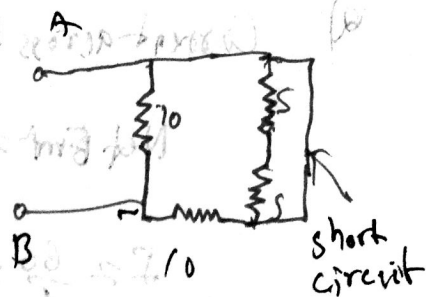
$$= \frac{3+2+1}{60} = \frac{6}{60} \Omega = 0.1 \Omega$$



Q) find Req b/w terminals A & B

Series $\rightarrow S+S = 10\Omega$

parallel Series $\rightarrow 10+10 = 20\Omega$



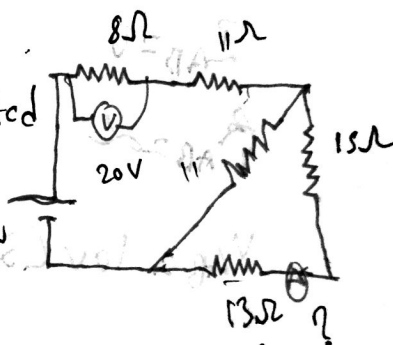
$$\frac{1}{R_{eq}} = \frac{1}{10} + \frac{1}{20}$$

$$= \frac{10+20}{10 \times 20} = \frac{30}{200} = \frac{3}{20} \Rightarrow R_{eq} = \frac{20}{3} = 6.6\Omega$$

$$= \frac{1}{R_{eq}} = \frac{1}{10} + \frac{1}{10} = \frac{2}{10} = \frac{1}{5} \Rightarrow R_{eq} = 5\Omega$$

Q) A battery of unknown EMF is connected across the resistances as shown in figure N

The voltage drop across 8Ω resistor is 20V. what will be the current reading in ammeter



$$I = \frac{V}{R}$$

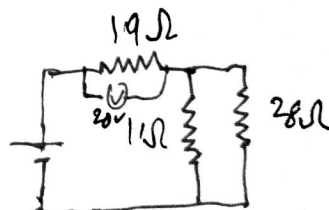
$$= \frac{20}{8} = 2.5A$$

$$I_1 = I \frac{R_2}{R_1 + R_2}$$

$$= 2.5 \times \frac{28}{39}$$

$$= 2.5 \times \frac{20}{39}$$

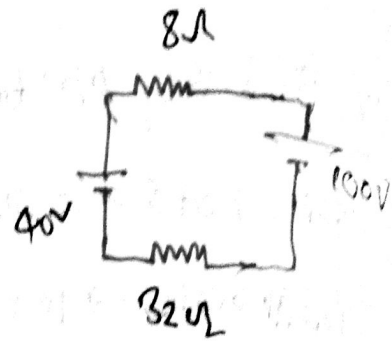
$$\approx 1.9A$$



Q) Current across the circuit

$$\text{Net EMF} = 100 - 40 = 60\text{V}$$

$$I = \frac{60}{40} = 1.5\text{ A}$$

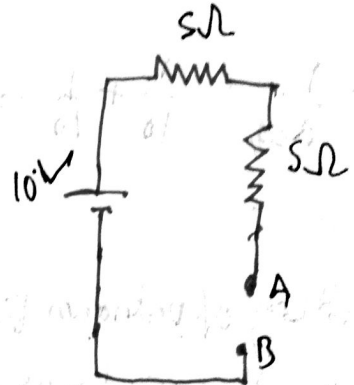


Q) Determine V_{AB}

$$V_{AB} = ?$$

$$I_{AB} = 0$$

$$R_{AB} = \infty$$



$$V_{AB} = 10\text{V (Source voltage)}$$

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Mesh Analysis

KVL

$$\sum E_{mf} + \sum V_D = 0$$

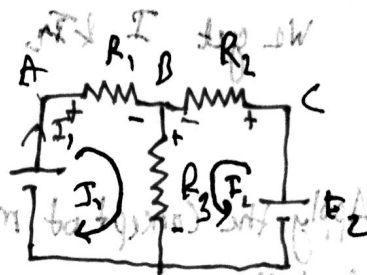
$$0 = R_1(I_1 + I_2) - R_2 I_1 - R_3 I_2 +$$

$$E_1 - (R_1 + R_2)I_1 - R_3 I_2 = -E_1$$

Step 1:- Identify loops and loop current

Loop 1: ABDA $\rightarrow I_1$

Loop 2: CBDC $\rightarrow I_2$



Step 2:- Express all branches in terms of loop currents

Branch currents depend on V

Loop currents do not depend on V

no of Eqn to be formed = no. of Independent V

Step 3:- Assign polarities for all E & V

Step 4:- Form the loop equations

Step 5:- Solve the loop equations for I_1 & I_2

Loop 1:

$- + \rightarrow$ voltage rise $\rightarrow +V$

$+ - \rightarrow$ voltage drop $\rightarrow -V$

$$+E_1 - I_1 R_1 - (I_1 + I_2) R_3 = 0$$

$$I_1 R_1 + I_1 R_3 + I_2 R_3 = E_1$$

$$I_1 (R_1 + R_3) + I_2 R_3 = E_1 \quad \text{--- (1)}$$

Loop 2:-

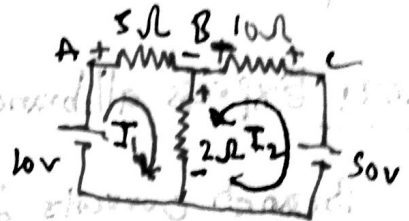
$$+E_2 - I_2 R_2 - (I_1 + I_2) R_3 = 0$$

$$= I_1 R_3 + I_2 (R_2 + R_3) = E_2 \quad \text{--- (2)}$$

by solving (1) and (2)

We get I_1 & I_2

Q) Apply the concept of mesh analysis to find the current



Step 1: There are 2 loops: $A \rightarrow B \rightarrow D \rightarrow A \rightarrow$ Loop 1 $\rightarrow I_1$

$C \rightarrow B \rightarrow D \rightarrow C \rightarrow$ Loop 2 $\rightarrow I_2$

Step 2: Branch currents are expressed in loop currents

Step 3: Polarity

Step 4: Loop equation $A \rightarrow B \rightarrow D \rightarrow A \rightarrow$

$$-5I_1 - 2(I_1 + I_2) = -10$$

$$7I_1 + 2I_2 = 10 \quad \text{--- (1)}$$

Loop $C \rightarrow B \rightarrow D \rightarrow C \rightarrow$

$$-10I_2 - 2(I_1 + I_2) + 50 = 0$$

$$-2I_1 - 12I_2 + 50 = 0$$

$$2I_1 + 12I_2 = 50 \quad \text{--- (2)}$$

Solving ① & ② in matrix form

$$\begin{bmatrix} 7 & 2 \\ 2 & 12 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 10 \\ 50 \end{bmatrix}$$

$$A \cdot x = B$$

$$|A|; A^{-1} = \begin{bmatrix} 10 & 2 \\ 50 & 12 \end{bmatrix} \quad x = \frac{|A \cdot x|}{|A|}$$

$$A_y = \begin{bmatrix} 7 & 10 \\ 2 & 50 \end{bmatrix}$$

$$y = \frac{|A_y|}{|A|}$$

$$x = \frac{\begin{bmatrix} 10 & 2 \\ 50 & 12 \end{bmatrix}}{\begin{bmatrix} 7 & 2 \\ 2 & 12 \end{bmatrix}}$$

$$I_1 = 0.25 \text{ A}$$

$$I_2 = 4.125 \text{ A}$$

Apply concept of mesh analysis & find

(loop equations)

$$10 - 5I_1 - 2(I_1 + I_2) = 0$$

$$= 10 - 5I_1 - 2I_1 + 2I_2 = 0$$

$$= 10 - 7I_1 + 2I_2 = 0$$

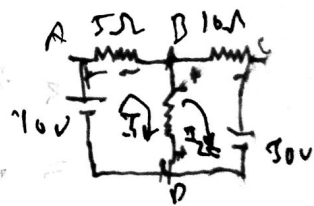
$$= 7I_1 - 2I_2 = 10 \quad \text{--- (1)}$$

loop CDB

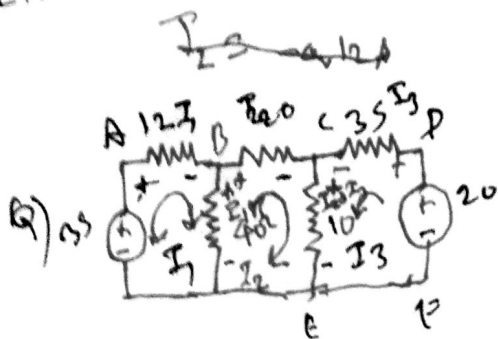
$$CDB - 10I_2 - 50 + 2(I_1 - I_2) = 0$$

$$= -10I_2 + 2I_1 - 2I_2 = 0$$

$$I_2 = 4.125 \text{ A}$$



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find branch currents using mesh analysis

Loop 1 ABEA $\rightarrow I_1$

Loop 2 BCED $\rightarrow I_2$

Loop 3 DEED $\rightarrow I_3$

$$\text{Loop 1 ABEA} \rightarrow -12I_1 - 40(I_1 - I_2) = -35$$

$$= -12I_1 - 40I_1 + 40I_2 = -35$$

$$= -52I_1 + 40I_2 = -35$$

$$= 52I_1 - 40I_2 = 35 \quad \text{--- (1)}$$

$$\text{Loop 2 BCED} \rightarrow -20I_2 - 10(I_2 - I_3) + 40(I_1 - I_2) = 0$$

$$= -20I_2 - 10I_2 + 10I_3 + 40I_1 - 40I_2 = 0$$

$$= 40I_1 - 70I_2 + 10I_3 = 0 \quad \text{--- (2)}$$

$$\text{Loop 3 DEED} \rightarrow -35I_3 - 10(I_2 - I_3) = 20$$

$$= -35I_3 - 10I_2 + 10I_3 = 20$$

① ② ③ in matrix form

$$\begin{bmatrix} 52 & -40 & 0 \\ 40 & -70 & -10 \\ 0 & 10 & 45 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 35 \\ 0 \\ 20 \end{bmatrix}$$

$$\Delta = -86600$$

$$\Delta I_1 = \begin{bmatrix} 35 & -40 & 0 \\ 0 & -70 & -10 \\ 20 & 10 & 45 \end{bmatrix} = -98750$$

$$I_1 = 1.14 \text{ A}$$

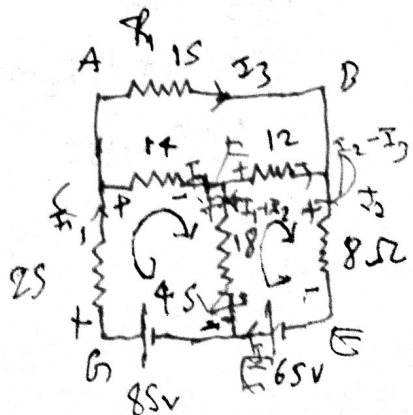
$$\Delta I_2 = \begin{bmatrix} 52 & 35 & 0 \\ 40 & 0 & -10 \\ 0 & 20 & 45 \end{bmatrix} = -52600$$

$$I_2 = 0.60 \text{ A}$$

$$\Delta I_3 = \begin{bmatrix} 52 & -40 & 35 \\ 40 & -70 & 0 \\ 0 & 10 & 20 \end{bmatrix} = -22600$$

$$I_3 = 0.30 \text{ A}$$

- 2) find current flowing via 18Ω
 Using mesh analysis
 CABDA
 loop 1 $\rightarrow$ ~~ABDA~~ $\rightarrow I_1$
 loop 2 $\rightarrow$ GCFE $\rightarrow I_2$
 loop 3 $\rightarrow$ EFDE $\rightarrow I_3$



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(25)

Loop 2 $\rightarrow$ GCPB $(I_1 - I_2)$

$$-25I_1 - 14(I_1 - I_2) = -$$

$$85 - 25I_1 - 14I_1 + 14I_2 - 18(I_1 - I_2) - 43 = 0 \quad \text{--- (1)}$$

Loop 3 $\rightarrow$ DCFD

$$18(I_1 + I_2) - 12(I_2 - I_3) - 8I_2 = -65 - 45$$

$$18I_1 + 18I_2 - 12I_2 + 12I_3 - 8I_2 = -110$$

$$18I_1 - 2I_2 + 12I_3 = -110$$

$$-18I_1 + 2I_2 - 12I_3 = 110 \quad \text{--- (2)}$$

Loop 4 $\rightarrow$ CABDFC

$$-15I_3 + 12(I_2 - I_3) + (I_1 - I_3)14 = 0$$

$$-15I_3 + 12I_2 - 12I_3 + 14I_1 - 14I_3 = 0$$

$$14I_1 + 12I_2 - 41I_3 = 0 \quad \text{--- (3)}$$

① continued

$$-25I_1 - 14I_1 + 14I_2 - 18I_1 + 18I_2 = -85 + 45$$

$$-25I_1 - 14I_1$$

$$-57I_1 + 18I_2 + 14I_3 = 40$$

$$57I_1 - 18I_2 - 14I_3 = 40 \quad \text{--- (1)}$$

$$Ax=b \quad \begin{bmatrix} 57 & -18 & -14 \\ -18 & 38 & -12 \\ 14 & 12 & -41 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 40 \\ 110 \\ 0 \end{bmatrix}$$

$$\Delta = -58818$$

$$\Delta I_1 = \begin{bmatrix} 40 & -18 & -14 \\ 110 & 38 & -12 \\ 0 & 12 & -41 \end{bmatrix}$$

$$= -156220$$

$$I_1 = 2.4A$$

$$\Delta I_2 = \begin{bmatrix} 57 & 40 & -14 \\ -18 & 110 & -12 \\ 14 & 0 & -41 \end{bmatrix}$$

$$= -271750$$

$$I_2 = 5.04A$$

$$\Delta I_3 = \begin{bmatrix} 57 & -18 & 40 \\ -18 & 38 & 110 \\ 14 & 12 & 0 \end{bmatrix}$$

$$= -132880$$

$$I_3 = 2.46A$$

$$\text{Current in } 18\Omega = I_1 - I_2$$

$$= 2.4 - 5.04$$

$$= -2.64A$$

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(27)

Nodal Analysis

- Based on KCL
- KCL states that algebraic sum of all currents meeting in a junction is equal to zero
- Here branch currents are expressed in nodal voltages
 $\therefore$ independent variable $\rightarrow$ nodal voltages
 dependent $\rightarrow$ branch current

apply KCL at ①

$$I_3 = I_1 + I_2 \quad \text{--- ①}$$

$$I_1 = \frac{\text{Pd b/w 1 \& 0}}{R \text{ b/w 1 \& 0}}$$

$$= \frac{V_1 - 0}{R_1} = \frac{V_1}{R_1}$$

$$I_2 = \frac{\text{Pd b/w 1 \& 2}}{R \text{ b/w 1 \& 2}}$$

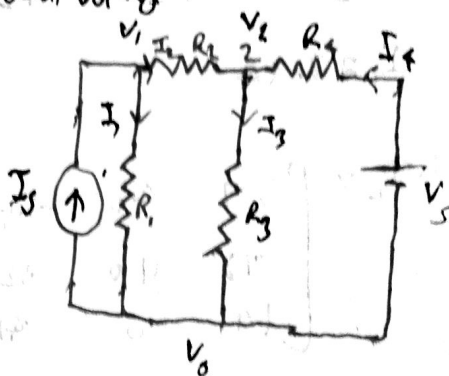
$$I_2 = \frac{V_1 - V_2}{R_2}$$

$$I_3 = \frac{V_1}{R_1} + \frac{V_1 - V_2}{R_2} \quad \text{--- ③}$$

as per KCL at ②

$$I_2 + I_4 = I_3$$

$$I_4 = \frac{\text{Pd 2 \& 3}}{R \text{ 2 \& 3}} = \frac{V_3 - V_2}{R_4} =$$



$$I_3 = \frac{V_2 - 0}{R_3}$$

$$2 = \frac{V_1 - V_2}{5} + \frac{V_1}{10}$$

$$\frac{V_1 - V_2}{R_2} + \frac{V_5 - V_2}{R_4} = \frac{V_2}{R_3} \quad \text{--- (3)}$$

$$2 = \frac{V_1}{5} - \frac{V_2}{5} + \frac{V_1}{10}$$

$$\frac{V_1}{R_2} - \frac{V_2}{R_2} + \frac{V_2}{R_4} - \frac{V_2}{R_3} = -\frac{V_5}{R_4}$$

$$2 = \left(\frac{1}{5} - \frac{1}{5} + \frac{1}{10} - \frac{1}{5}\right) V_1 + \frac{V_5}{5}$$

$$V_1 \left(\frac{1}{R_2}\right) - V_2 \left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right) = -\frac{V_5}{R_4} \quad \text{--- (4)}$$

By solving (3) & (4)

V_1 & V_2

I_1, I_2, I_3, I_4

V_1 & V_2 Independent

apply KCL at (1)

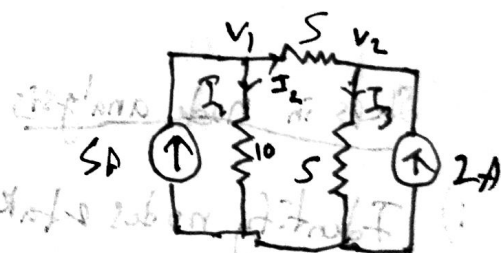
$$I_1 + I_2 = 5 \quad \text{--- (1)}$$

$$I_2 + 2 = I_3 \quad \text{--- (2)}$$

$$I_1 = \frac{V_1 - 0}{10}$$

$$I_2 = \frac{V_1 - V_2}{5}$$

$$I_3 = \frac{V_2 - 0}{5}$$



Apply KCL

Apply KVL to loop 1 & 2

Apply KVL to loop 3

Apply KVL to loop 4

Apply KVL to loop 5

$$\frac{V_1}{10} + \frac{V_1 - V_2}{5} = 5$$

$$\frac{V_1}{10} + \frac{V_1}{5} - \frac{V_2}{5} = 5$$

$$V_1 \left(\frac{1}{10} + \frac{1}{5} \right) - V_2 \left(\frac{1}{5} \right) = 5 \quad \text{--- (3)}$$

$$\frac{V_1 - V_2}{5} + 2 = 2V_2$$

$$\frac{V_1}{5} - \frac{V_2}{5} - \frac{V_2}{5} = -2$$

$$V_1 \left(\frac{1}{5} \right) - V_2 \left(\frac{1}{5} + \frac{1}{5} \right) = -2 \quad \text{--- (4)}$$

Solve (3) & (4)

Obtain V_1 & V_2

Steps in node analysis

- 1) Identify nodes & take 1 node as reference node
- 2) Express all branch current in terms of nodal voltages
- 3) Assign polarities
- 4) Apply KCL
- 5) Find equations and solve

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Unit -2

(30)

Network TheoremSuperposition Theorem

- Used when more than one source of EMF is present
- Linear element $\rightarrow$ elements which obey ohm's law
- Bilateral element $\rightarrow$ Properties of element are same in both direction
- ~~Algebraic sum of all~~

- Applicable for linear and bilateral networks
- The current which flows at any point in the network is the algebraic sum of all the currents which would flow at that point in the network if each source were considered separately

- For time being, all other sources were replaced by their internal resistances

- If internal resistance is not given:

Replace V's by short circuit

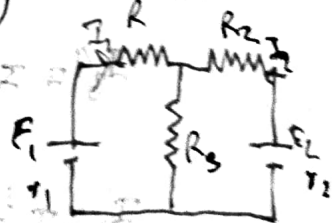
Replace I's by open circuit

Step 1: Replace second source by internal resistance

Step 2: Redraw the network and replace the first source by internal resistance

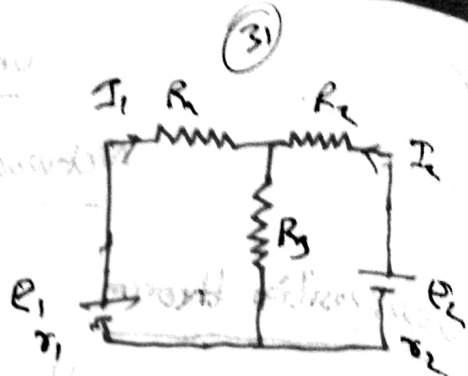
Step 3: Add or subtract depending on the direction

Step 4: If I_4 is there, $I_4 = I_1 + I_2 + I_3$



V_s by short circuit

I_s by open circuit

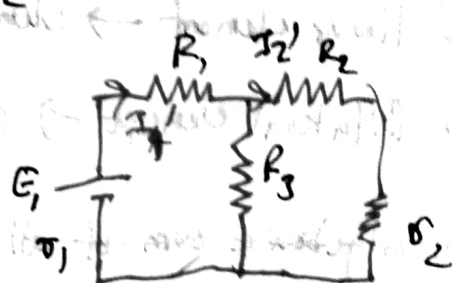


Redrawing circuit by replacing E_2

$$I_1' = \frac{E_1}{r_1 + R_1 + (R_2 + R_3) \parallel R_3}$$

$$I_2' = I_1' \times \frac{R_3}{R_3 + R_2 + r_2}$$

$$I_3' = I_1' - I_2'$$



Replacing E_1

$$I_2'' = \frac{E_2}{R_2 + r_2 + (R_3 \parallel (r_1 + R_1))}$$

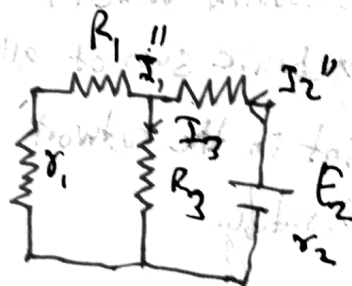
$$I_1'' = I_2'' \times \frac{R_3}{R_3 + R_1 + r_1}$$

$$I_3'' = I_2'' - I_1''$$

$$I_1 = I_1' - I_1''$$

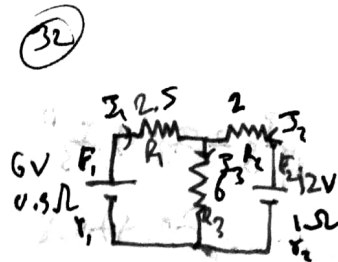
$$I_2 = I_2' - I_2''$$

$$I_3 = I_3' + I_3''$$



a)

$$\begin{aligned}
 R_1 &= 2.5\Omega \\
 R_2 &= 2\Omega \\
 R_3 &= 6\Omega \\
 r_1 &= 0.5\Omega \\
 E_1 &= 6V \\
 r_2 &= 1\Omega \\
 E_2 &= 12V
 \end{aligned}$$



Redrawing the circuit by replacing E_2

$$\begin{aligned}
 I_1' &= \frac{E_1}{r_1 + R_1 + ((R_2 + r_2) \parallel R_3)} \\
 &= \frac{6}{0.5 + 2.5 + ((2 + 1) \parallel 6)(6 \parallel 3)} \\
 &= \frac{6}{0.5 + 2.5 + (\frac{1}{\frac{1}{2} + \frac{1}{6}})} = \frac{6}{5} = 1.2A
 \end{aligned}$$



$$I_2' = \frac{1.2 \times 6}{6 + 2 + 1} = 0.8A$$

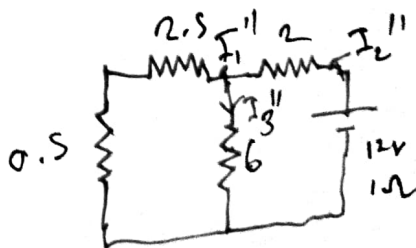
$$I_3' = 1.2 - 0.8 = 0.4A$$

Replacing the ~~first~~ E_1

$$\begin{aligned}
 I_2'' &= \frac{12}{2 + (3 \parallel 6)} \\
 &= \frac{12}{5} = 2.4A
 \end{aligned}$$

$$I_1'' = \frac{2.4 \times 6}{6 + 3} = 1.6A$$

$$\begin{aligned}
 I_3'' &= I_2'' - I_1'' \\
 &= 2.4 - 1.6 = 0.8A
 \end{aligned}$$



$$I_3 = I_3' + I_3''$$

$$= 0.4 + 0.8$$

$$= 1.2A$$

$$I_1 = I_1' - I_1''$$

$$= 1.2 - 1.6$$

$$= -0.4A$$

$$I_2 = I_2' - I_2''$$

$$= 2.4 - 0.8$$

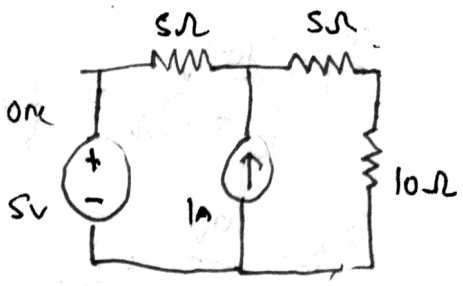
$$= 1.6A$$

2/10/23

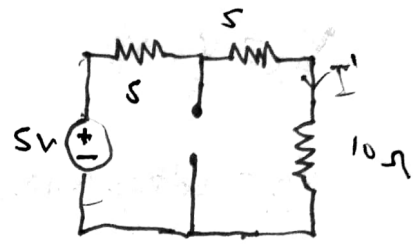
34

Q) Find current via 10Ω resistor using superposition theorem

- Redraw the network by considering one source at a time
other sources are replaced by their internal resistances



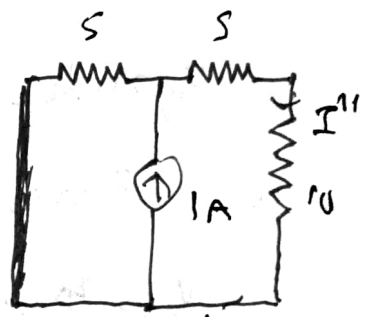
$$I' = \frac{5}{5+10} = \frac{5}{20} = \frac{1}{4} = 0.25A$$



Consider 1A alone

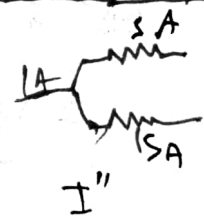
5V is replaced by short circuit

$$I'' = 1 \times \frac{5}{5+10} = \frac{5}{20} = \frac{1}{4} = 0.25A \quad \text{S.C.}$$



Step 3

$$I = I' + I'' = 0.5A$$

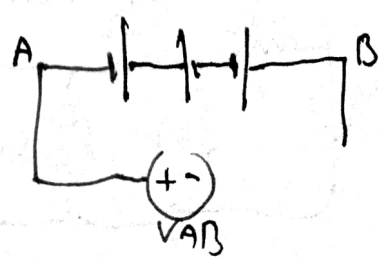
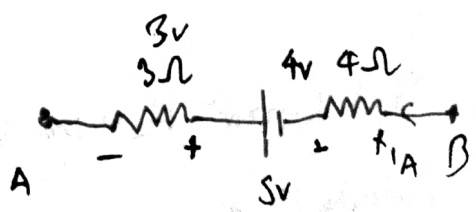


Q) $V_{AB} = ?$

$$+3V - 5V + 4V + V_{AB} = 0$$

$$2V + V_{AB} = 0$$

$$V_{AB} = -2V$$



$$V_{AB} = ?$$

$$I_1 = \frac{10V}{(10+20)\Omega} = \frac{1}{3} A$$

$$I_2 = \frac{10V}{20\Omega} = \frac{1}{2} A$$

$$V_{AB} = V_A - V_B$$

V_A = Voltage across 20Ω

$$= 20 \times \frac{1}{3} = \frac{20}{3} V$$

V_B = Voltage across 40

$$= 40 \times \frac{1}{2} = \frac{40}{2} V$$

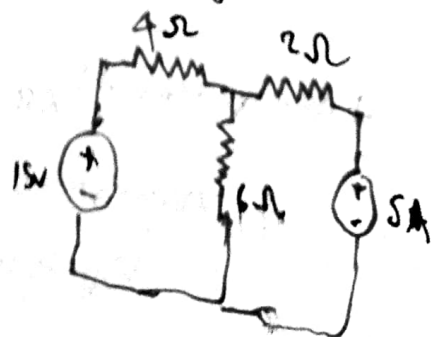
$$V_{AB} = \frac{20}{3} - \frac{40}{2}$$

$$= \frac{40 - 120}{21} = -\frac{80}{21} V$$



6) Find Current flowing V in a 6Ω using Superposition

Replacing SA with open circuit



$$I' = \frac{15}{4+6}$$

$$= \frac{15}{10} = 1.5A$$

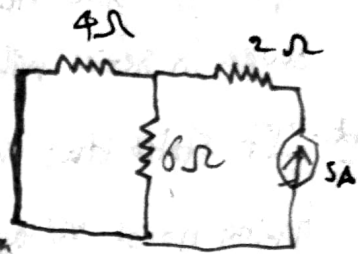
Replacing current S_L

$$I'' = 5 \times \frac{4}{4+6}$$

$$= 5 \times \frac{4}{10} = \frac{20}{5} = 2A$$

$$I = I' + I''$$

$$= 1.5 + 2 = 3.5A$$



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Thevenin's Theorem

Definition: Thevenin's Theorem provides a mathematical technique for replacing a given network by a simple ~~to~~ single voltage source in series with resistance.

Statement: It states that any 2 terminal linear, bilateral network having no AC voltage sources and current sources and resistances can be replaced by simple equivalent circuit consisting of a single voltage source in series with resistance where the value of voltage source is equal to open circuit voltage across the 2 terminals of the network and resistance is equal to equivalent resistance of the network measured between 2 terminals of the network with all sources replaced by their internal resistances.

Steps for applying Thevenin's theorem

Step 1: Redraw the network by removing R_L

Step 2: Calculate open circuit voltage V_{oc} or V_{th}

$$V_{oc} = V_{AB} = V_{th}$$

$$V_{th} = V_{AB} = \text{Voltage across } R_2$$

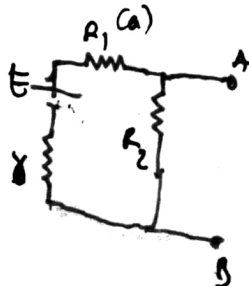
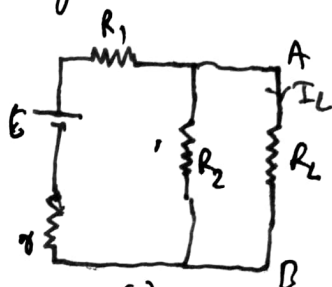
$$I = \frac{E}{R_1 + R_2}$$

$$V_{th} = I \cdot R_2 = V_{AB}$$

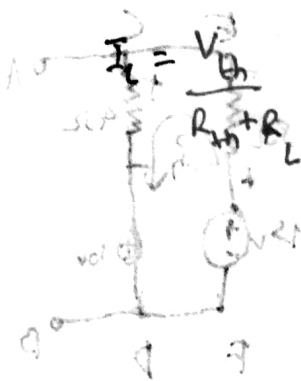
Step 3: Calculate R_{th} or R_{oc}

Redraw the circuit & replace E with r

$$R_{oc} = R_2 \parallel (R_1 + r)$$

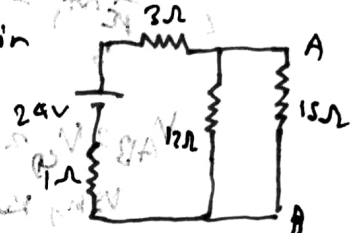


Step 4: Replace the entire network with Thevenin equivalent network by connecting R_L



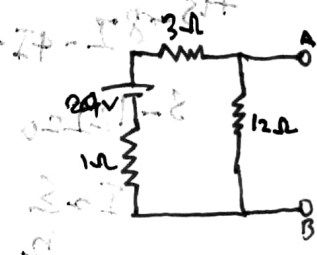
Q) Find current flowing via 15Ω using Thevenin theorem

A) Redrawing the network by removing 15Ω



$$I = \frac{E}{r + R_1 + R_2}$$

$$= \frac{24}{1 + 3 + 12} = \frac{24}{16}$$



$$V_{th} = I \cdot R_2$$

$$= \frac{24}{16} \times 12 = 18V$$

Redrawing circuit by replacing $24V$ with r



$$R_{oc} = R_2 \parallel (R_1 + r)$$

$$= 12 \parallel (3 + 1)$$

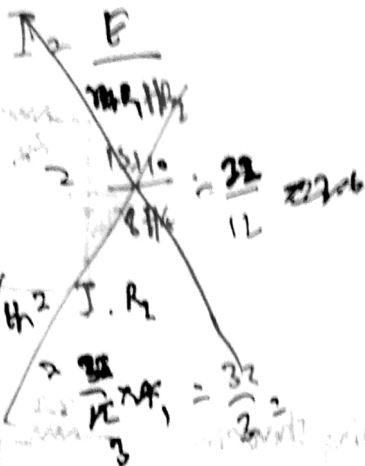
$$= 12 \parallel 4$$

$$\frac{1}{R_{oc}} = \frac{1}{12} + \frac{1}{4}$$

$$R_{oc} = 3\Omega$$

$$I_L = \frac{V_{th}}{R_{th} + R_L} = \frac{18}{3 + 15} = \frac{18}{18} = 1A$$

Q) obtain thevenin's equivalent network for the given network.



$$V_{AB} = V_{CD} = V_{EF}$$

using KVL

$$+15 - 8I - 4I - 10 = 0$$

$$5 - 12I = 0$$

$$I = \frac{5}{12}$$

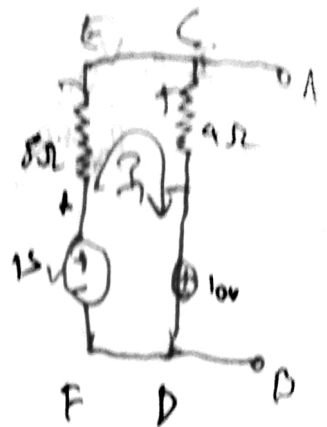
Voltage drop across $4\Omega = I \times \frac{5}{12} = \frac{5}{3} V$

$$V_{AB} = 10 + \frac{5}{3} = \frac{35}{3} V = 11.6V$$

$$R_{th} = R_2 \parallel R_1$$

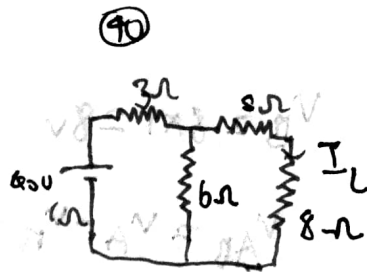
$$= 4 \parallel 8$$

$$= \frac{1}{4} + \frac{1}{8} = \frac{3}{8} = 2.6\Omega$$



5/10/23

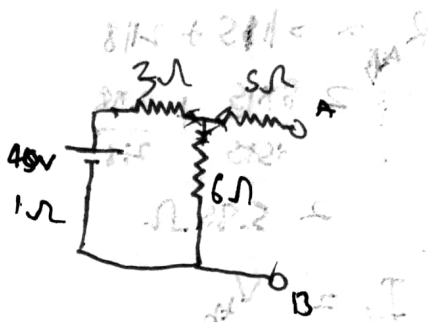
Q) Find current in 8Ω using thevenin's theorem



c) Remove 8Ω & redraw the network

$$I = \frac{V}{R_{th} + R_L}$$

$$= \frac{40}{8 + 6} = \frac{40}{14} = 2.857 \text{ A}$$



$$V_{th} = I \cdot R_L = 2.857 \times 8 = 22.857 \text{ V}$$

$$R_{th} = (3 + 3) \parallel (1 + 6) = 6 \parallel 7 = 3.23 \Omega$$

$$= 3.23 \Omega$$

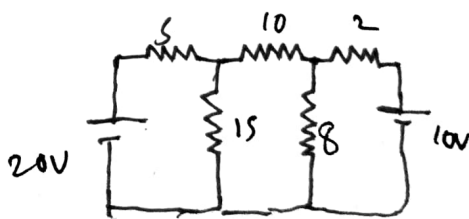
$$= 3.23 \Omega$$

$$2.475$$

$$= 7.4 \Omega$$

$$I_L = \frac{V_{th}}{R_{th} + R_L} = \frac{22.857}{3.23 + 8} = 2.09 \text{ A}$$

Q) Find current in 10Ω resistor using thevenin



A) Redraw the circuit by removing R_L

Using KVL

$$20V - 5I - 15I = 0$$

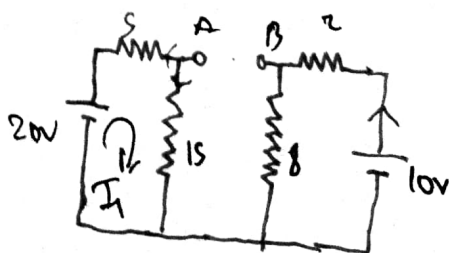
$$-20I = -20$$

$$I = 1 \text{ A}$$

|||

I on other side = 1A

$$V_A = 20 - 5 \times 1 = 15 \text{ V}$$



$$V_B = 8 \times 1 = 8V$$

$$V_{AB} = V_A - V_B = 15 - 8 = 7V$$

$$R_{AB} = 5 \parallel 5 + 2 \parallel 8$$

$$= \frac{5 \times 5}{5+5} + \frac{2 \times 8}{2+8}$$

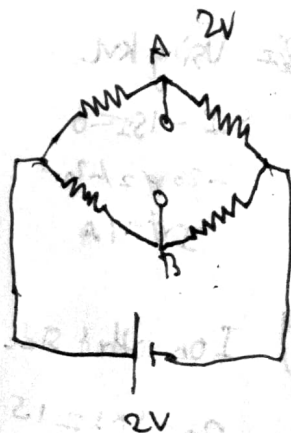
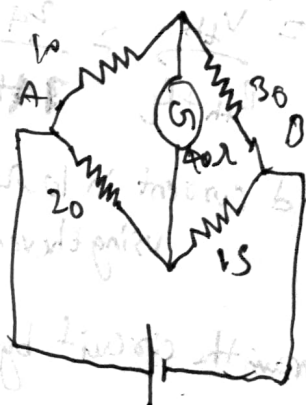
$$= 5.35 \Omega$$

$$I_L = \frac{V_{th}}{R_{th} + R_L}$$

$$= \frac{7}{5.35 + 10} = 0.45A$$

Q) Find current flowing through the galvanometer having internal resistance

20

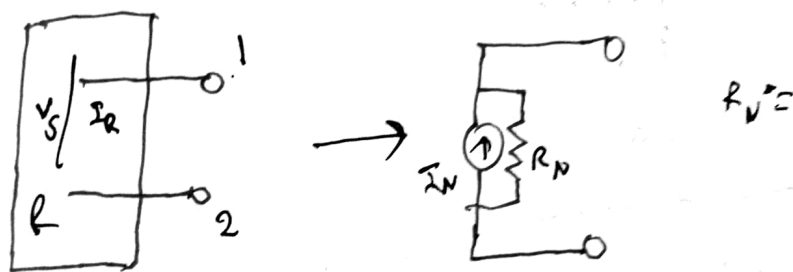


Norton's Theorem:-

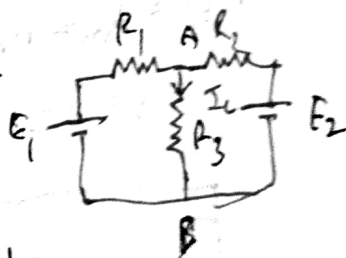
statement:- Any 2 terminal linear active bilateral network containing multiple number of ~~src~~ energy sources and resistances can be replaced by a simple network containing a current source in parallel with the resistance.

The current source is equal to current which would flow through the short circuit placed across the 2 terminals

Parallel resistance ^(R_N) ^{or} is the resistance of the network when looked from the open circuit terminals with all energy sources replaced by their internal resistances



Step 1) Remove the resistor & replace it with short circuit



Step 2) Calculate I_{sc} using a suitable

theorem here super position

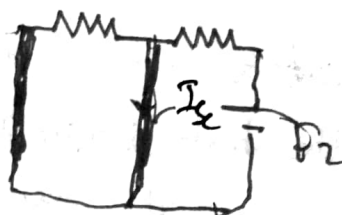
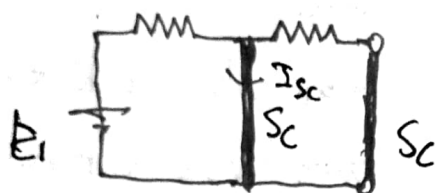
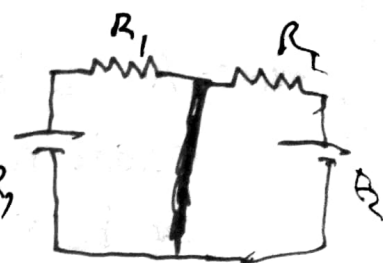
Step 3:- Calculate R_N or R_{th}

Steps:- Redraw the circuit by removing voltage source

Steps:- Find I_L

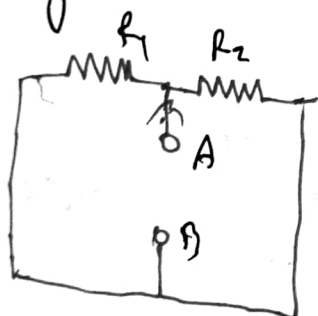
R_2 is replaced by short circuit

Calculate I_{sc} using ~~short~~ superposition theorem



$$I_{sc} = I_{sc1} + I_{sc2}$$

calculating R_N



$$R_{AB} = R_{th} = R_N$$

$$R_1 \parallel R_2$$



$$I_L = I_{sc} \frac{R_N}{R_N + R_L}$$

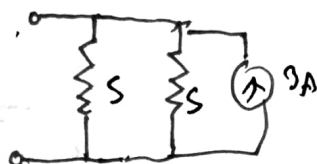
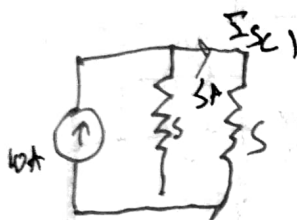
11/10/23

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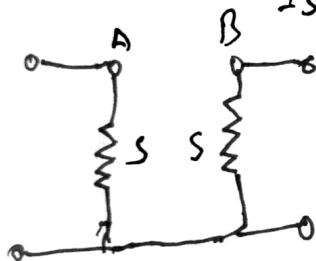
1) find current I flowing through 3Ω resistor using norton's theorem.

Replacing resistor with short circuit

Applying superposition & calculate I_{sc}

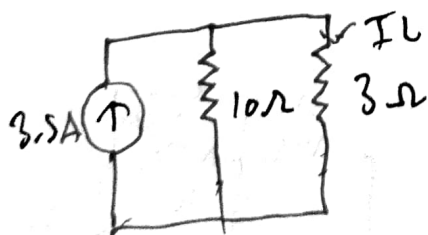


$$I_{sc} = 5 - 1 - 5 = 3.5A$$

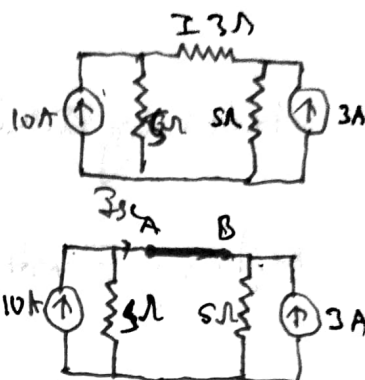


$$R_{AB} = 10\Omega$$

Redrawing norton's circuit

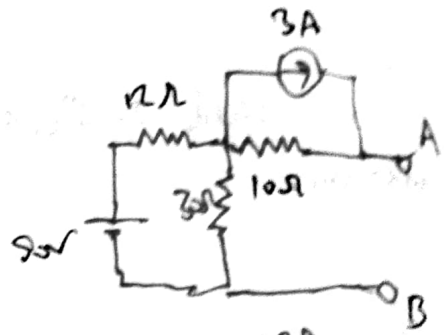


$$I_L = I_{sc} \frac{R_N}{R_N + R_L} = 3.5 \times \frac{10}{10 + 3} = \frac{35}{13} = 2.69A$$



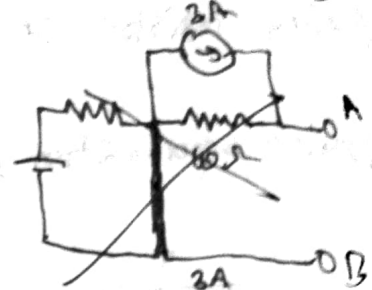
(2)

Find Norton equivalent circuit with A & B



Redrawing circuit by removing 30Ω

Replacing E with internal



$$(30 \parallel 12) + 10$$

$$\frac{30 \times 12}{42} + 10 = 18.5 \Omega$$

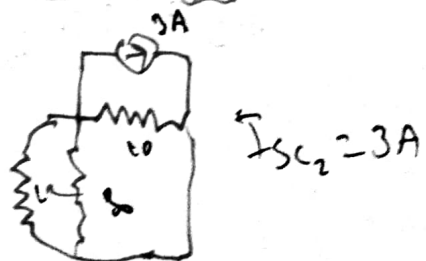
$$R_{eq} = (10 \parallel 30) + 12$$

$$= \frac{10 \times 30}{40} + 12 = 19.5 \Omega$$

$$I = \frac{50}{19.5} = 2.5A$$

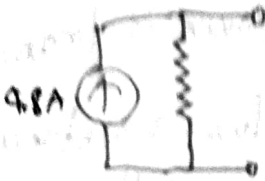
$$I_{sc1} = 2.5 \times \frac{30}{10+30}$$

$$= 2.5 \times \frac{3}{4} = 1.875A$$



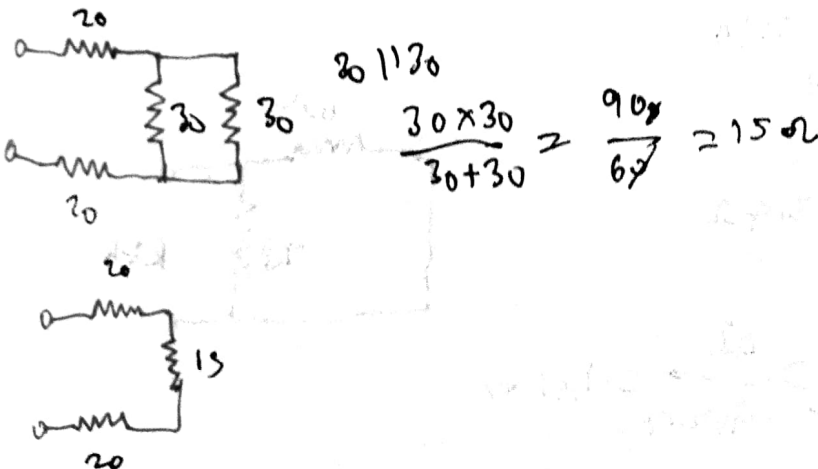
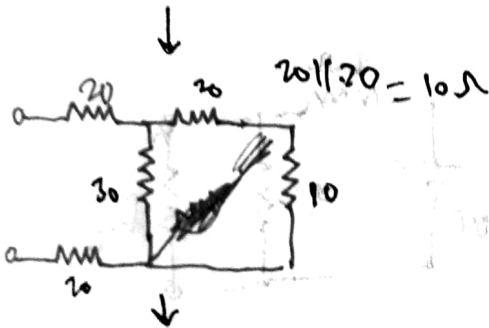
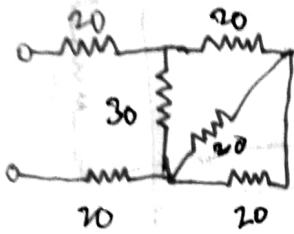
$$1.87 + 3 = 4.87 \text{ A}$$

$$R_N = 16.5 \Omega$$



Q) Find R_{AB} using network reduction technique

redrawing by combining 10Ω



$$= 55 \Omega$$

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Maximum Power Transfer Theorem

Statement:- In DC circuits maximum power is transferred from source to the load when load resistance is made equal to internal resistance of the source as looked from load terminals with load removed and sources replaced by their internal resistances

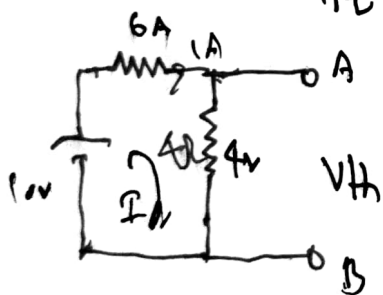
Steps

We need theorem for MPTT

1) Calculate R_{th} at P_{max}

2) Calculate V_{th}

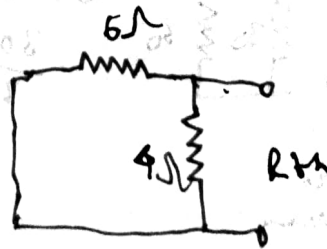
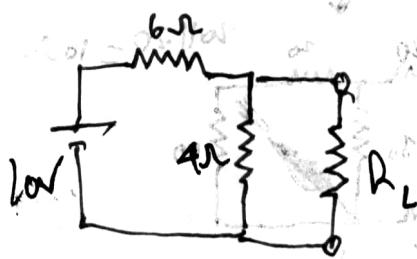
$$3) P_{max} = \frac{V_{th}^2}{4R_L}$$



$$I = \frac{10}{6+4} = 1A$$

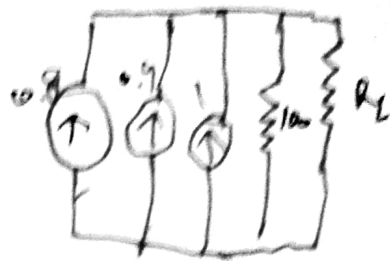
$$R_L = R_{th} = 2.4\Omega$$

$$P_{max} = \frac{V_{th}^2}{4R_L} = \frac{4^2}{4 \times 2.4} = 1.66W$$



(98)

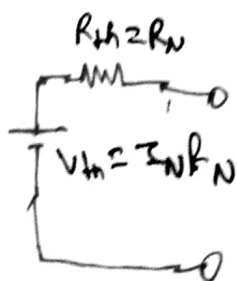
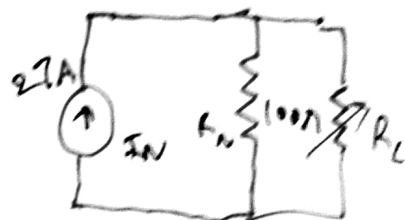
- a) calculate
- R_L at P_{max}
 - V_{th}
 - V_L
 - P_{max}
 - I_L



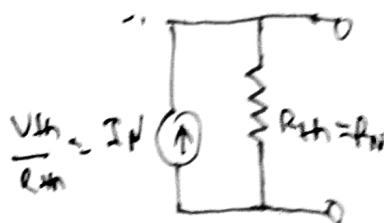
$R_L = 100$ Since only one resistor
combine 3 current sources into one

Can be converted into Norton

(Circuit)



$\Rightarrow$



$$V_{th} = 2.7 \times 100 = 270V$$

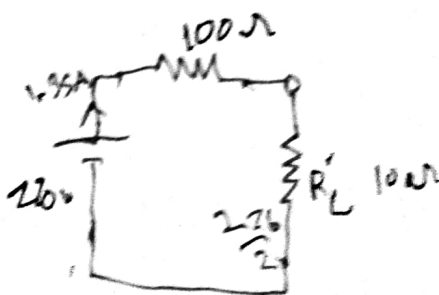
Converting to thevenin

$$R_L \text{ at } P_{max} = 100\Omega$$

$$V_L = 135 = \frac{V_{th}}{2}$$

$$I_L = 1.35$$

$$P_{max} = 182.25W$$



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Unit - 3

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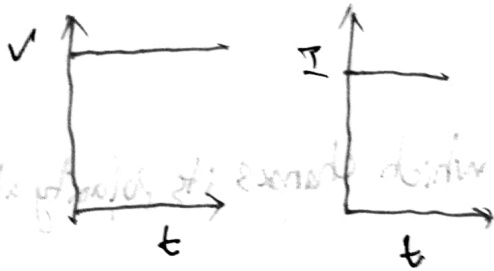
1- ϕ AC circuits

more info

There are 2 types of current:



a) Direct current



potential difference

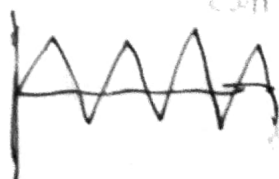
to provide the energy to drive the circuit to do work. It is the flow of electric charge that carries the energy from the source to the load.

b) Alternating current

Types of waves:

- 1) triangular
- 2) square
- 3) Sine wave
- 4) complex

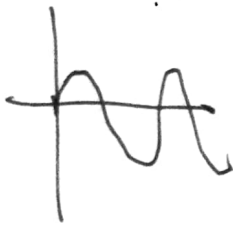
Triangle wave:



Square wave:



Sine wave



Alternating voltage

- It is the type of voltage which changes its polarity at regular intervals of time

Reasons to use AC

- Use of DC is limited
- Production of AC is easier than DC
- AC Generator produces ~~are~~ more power
- Rating of AC generator $>$ Rating of DC generator
- Transformers use AC voltage, we can adjust voltage
- AC motors are cheaper than DC

1- ϕ (Single phase) $\rightarrow$ used for homes

3- ϕ (Three phase) $\rightarrow$ Industries

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Sine wave is preferred over another waves because (i) integral and derivative of sine wave is again sine wave, which makes analysis easy

(ii) Sine wave causes least disturbance in the circuit

voltages and currents are represented using lower case letters in AC because the polarity changes in AC.

(iii) It is easy to produce sine waves

Formula for R

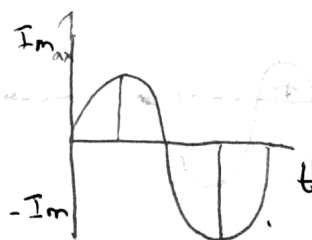
$$V = IR$$

Formula for L

$$V = L \frac{di}{dt}$$

Formula for C

$$V = \frac{1}{C} \int i dt$$



$$i = I_{\max} \sin \omega t$$

$$\omega t = 90 \quad i = I_{\max}$$

$$\omega t = 180 \quad i = 0$$

$$\omega t = 270 \quad i = -I_{\max}$$

$$\omega t = 360 \quad i = 0$$

$$V = V_{\max} \sin \omega t$$

Generation of Alternating voltages and currents

(i) We can generate AC by rotating a coil at constant angular velocity in a uniform magnetic field

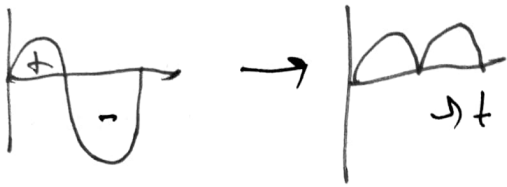
(ii) by rotating a magnetic field at a constant angular velocity within a coil

To take out current or power from moving coil, we need brushes

To consume the generated power, we use a resistor.

Nature of EMF generated in conductor/coil is always AC

Commutator & brush convert AC to DC



Sine wave is formed as the conductor's position changes

Equation of AC & AV

$$V = V_{\max} \sin \omega t$$

$$V_{\max} = n \Phi_{\max} \omega$$

$$I = I_{\max} \sin \omega t$$

more no of turns = more EMF

Sine wave can be represented using

- i) Rectangular
- ii) Polar
- iii) trigonometric
- iv) exponential

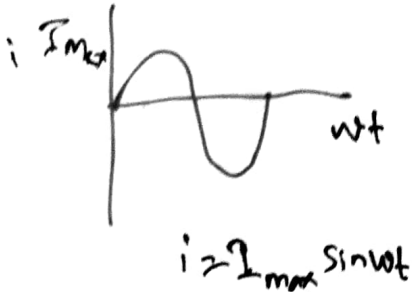
$\omega \rightarrow$ Angular velocity

$\Phi \rightarrow$ flux

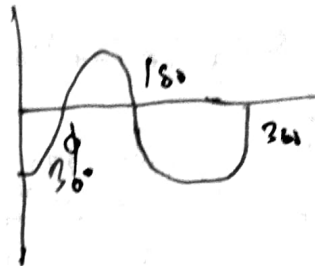
$n \rightarrow$ no of turns

Phasor

- Phasor is a vector used to represent sinusoidal signal
- Magnitude of it represents peak value of voltage & current



If passing via origin



$$i = I_{max} \sin (wt + \phi)$$

If not passing via origin

Transfer

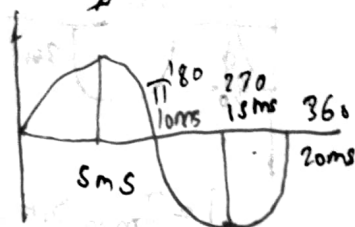
24/23

(55)

Time period of AC

$$\omega = 2\pi f$$

We use supply in India



$$\text{Time period } (T) = \frac{1}{f} = \frac{1}{50} = 20 \text{ ms}$$

a) An AC voltage is given by $V = 500 \sin(314t)$ find instantaneous values of voltages at $t = 7 \text{ ms}$ & 11 ms

A) given:

$$V = 500 \sin(314t) = 500 \sin(180t)$$

$t = 7 \text{ ms} \text{ \& } 11 \text{ ms}$

$$\Rightarrow V = 500 \sin\left(\frac{180}{360} \times 7 \times 10^{-3}\right) \text{ at } 7 \text{ ms}$$

$$= 1414 \text{ V}$$

At 11ms

$$V = 500 \sin\left(\frac{180}{360} \times 11 \times 10^{-3}\right)$$

Phase displacement

If we compare 2 waves

$$v = \sin(\omega t)$$

&

$$v = \sin(\omega t + 30^\circ)$$

We can notice that there is a phase diff.

This 30° is the phase displacement

Phasor representation

AC can be repⁿ in

i) Rectangular form $\rightarrow a + jb$

ii) Trigonometric form $\rightarrow v \cos \theta + j v \sin \theta$

iii) Exponential form $\rightarrow v e^{j\theta} = v \cos \theta + j v \sin \theta$

iv) Polar form $\rightarrow v \angle \theta$

We only use rectangular & polar form for analysis

We can use rectangular for Addition & Subtraction

We can use polar for multiplication & division

We have to use complex mode for calculations

$$\begin{aligned} (a + jb) + (c + jd) &= (a + jb) - (c + jd) \\ (a + c) + j(b + d) &= (a - c) + j(b - d) \end{aligned}$$

Polar form:-

$$\vec{A}_1 = |A_1| \angle \theta_1$$

$$\vec{A}_2 = |A_2| \angle \theta_2$$

$$A_1 A_2 = |A_1| |A_2| \angle (\theta_1 + \theta_2)$$

$$\frac{\vec{A}_1}{\vec{A}_2} = \frac{|A_1|}{|A_2|} \angle (\theta_1 - \theta_2)$$

Converting Rectangular to polar form

$$\vec{A} = 3 + j4$$

$$|A| \angle \theta = ?$$

$$|A| = \sqrt{3^2 + 4^2} = 5$$

$$\theta = \tan^{-1} \frac{4}{3} = 53.13^\circ$$

Converting Polar to Rectangular form

$$\vec{A} = 5 \angle 53.13^\circ$$

$$5 (\cos(53.13^\circ) + j \sin(53.13^\circ))$$

$$= 3 + j4$$

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(58)

Problems on phasors

$$\bar{A} = a_1 + jb_1$$

$$\bar{B} = a_2 + jb_2$$

$$\begin{aligned}\bar{A} + \bar{B} &= (a_1 + jb_1) + (a_2 + jb_2) \rightarrow \text{Addition in rectangular} \\ &= (a_1 + a_2) + j(b_1 + b_2)\end{aligned}$$

$$\bar{A} - \bar{B} = (a_1 - a_2) + j(b_1 - b_2) \rightarrow \text{Subtraction in rectangular}$$

$$|\bar{A} + \bar{B}| = \sqrt{(a_1 + a_2)^2 + (b_1 + b_2)^2}$$

$$\theta = \tan^{-1} \left(\frac{b_1 - b_2}{a_1 + a_2} \right)$$

multiplication in rectangular

$$\bar{A} \cdot \bar{B} = (a_1 + jb_1)(a_2 + jb_2)$$

$$= a_1 a_2 + j^2 b_1 b_2 + j(a_1 b_2 + b_1 a_2)$$

$$= (a_1 a_2 - b_1 b_2) + j(a_1 b_2 + b_1 a_2)$$

$$\text{mag of } C = \sqrt{(a_1 a_2 - b_1 b_2)^2 + (a_1 b_2 + b_1 a_2)^2}$$

Multiplication in polar form

$$A = a_1 + jb_1 = A \angle \alpha = A e^{j\alpha} \text{ where } \alpha = \tan^{-1}(b_1/a_1)$$

$$B = a_2 + jb_2 = B \angle \beta = B e^{j\beta} \text{ where } \beta = \tan^{-1}(b_2/a_2)$$

$$\therefore AB = A \angle \alpha \times B \angle \beta$$

$$A \angle \alpha \times B \angle \beta = AB \angle (\alpha + \beta)$$

Division in polar ^{or}

$$\frac{A}{B} = \frac{A \angle \alpha}{B \angle \beta} = \frac{A}{B} \angle (\alpha - \beta)$$

Q) Perform operation & express answer in polar

$$5 \angle 30^\circ + 8 \angle -30^\circ$$

$$A) \quad 5 \angle 30^\circ = 4.33 + j2.5$$

$$8 \angle -30^\circ = 6.93 - j4$$

$$(4.33 + 6.93) + j(2.5 - 4)$$

$$= 11.26 + j1.5$$

$$= \sqrt{11.26^2 + 1.5^2}$$

$$\theta = \tan^{-1} \left(\frac{-1.5}{11.26} \right)$$

$$= \tan^{-1} (-0.1332) = 11.35 \angle 7.6^\circ$$

Q) Subtract vectors from one another

$$A = 30 \angle 52^\circ \text{ and } B = -3$$

Q) Express $20e^{-j2\pi/3}$ in polar & rectangular

Polar

$$20 \angle -120^\circ$$

Rectangular

$$a = 20 \cos(-120^\circ) = -10; b = 20 \sin(-120^\circ) = -17.32$$

$$\therefore \text{Expression is } = (-10 - j17.32)$$

Ex 2- max current in sinusoidal current is 10A. What is instantaneous current at 45° ?

$$i = I_{\max} \sin \theta \text{ or } \sin \omega t$$

given

$$I_{\max} = 10 \text{ A}, \theta = 45^\circ$$

$$i = 10 \times \sin 45^\circ$$

$$= 7.07 \text{ A}$$

$$\text{at } \theta = 60^\circ$$

$$i = 10 \sin 60^\circ$$

$$i = 10 \sin 60^\circ$$

$$= 10 \times \frac{\sqrt{3}}{2} = 5\sqrt{3}$$

Ex: write mathematical expression for 50 Hz sinusoidal voltage of peak value 80 V. Sketch the wave form versus time t

A) given

$$f = 50 \text{ Hz}; V_m = 80 \text{ V}; \omega = 2\pi f = 2\pi \times 50 = 314 \text{ rad/s}$$

$$V = V_m \sin \omega t = 80 \sin 314t$$

$$V = 80 \sin 314t$$

$$\text{At } t = 5 \text{ ms} = 5 \times 10^{-3}$$

$$V = 80 \sin(314 \times 5 \times 10^{-3})$$

$$= 80$$

eg:- AC is given by $i = 10 \sin 942t$

Determine time taken from $t=0$ for the current to reach a value of 6 A for a first & second time

A)

$$6 = i = 10 \sin 942t$$

$$6 = 10 \sin 942t$$

$$\Rightarrow \sin 942t = 6/10 = 0.6$$

$$942t = \sin^{-1} 0.6 = 0.643 \text{ rad}$$

$$t = \frac{0.643}{942}$$

$$= 0.68 \times 10^{-3} \text{ s} = 0.68 \text{ ms}$$

$$f = \frac{942}{2\pi} = 150 \text{ Hz}$$

Time period of wave $= \frac{1}{150}$

$\therefore$ Time taken to reach $= 6.66 \times 10^{-3} \text{ s}$

+ 6 A for 2nd time $= 6.66 \text{ ms}$

$= 0.68 + \text{time period} = 0.68 + 6.66 = 7.34 \text{ ms}$

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AC Terminology

Time period $\rightarrow$ Time taken to form 2 Sin. waves

waveform $\rightarrow$ Shape of the curve obtained by plotting the instantaneous values of current or voltage

~~3.1~~

Instantaneous value $\rightarrow$ The value of alternating quantity at any instant

Cycle $\rightarrow$ one complete set of positive & negative values of an alternating quantity

Frequency $\rightarrow$ Number of cycles that occur in one second is called frequency

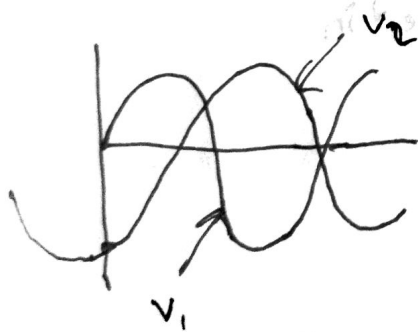
Amplitude $\rightarrow$ The maximum value attained by alternating quantity

Phase of particular value $\rightarrow$ fractional part of time period or cycle through which the quantity has advanced from the selected zero position of reference

- i) phase depends upon instant ~~from~~ from which time is measured
- ii) Alternating quantity (V or I) is completely known if we know its
- (a) max value
 - (b) frequency
 - (c) phase

Angle of phase difference (ϕ) $\rightarrow$ angle b/w 2 zero points

lagging and leading



If 2 waveforms are not starting at the same point then there is a phase difference θ

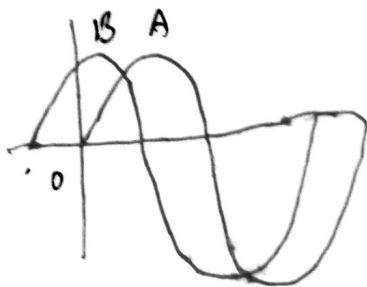
Phase diff is only obtained when frequency is same

V_1 is leading with respect to V_2
or

V_2 is lagging with respect to V_1

$i = I_{max} \sin \omega t$ is valid when wave is passing via origin

$i = I_{max} \sin(\omega t + \theta)$ is valid when wave form isn't passing via origin



B is leading w.r.t A as it reaches maximum first

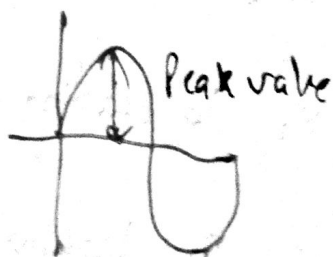
~~Explain~~

Alternating voltage can be expressed in

- 1) Peak value
- 2) Avg value
- 3) RMS value
- 4) Peak to peak value

Peak to peak value

Maximum amplitude obtained by alternating quantity



Peak value is used for insulation design

We use RMS to specify alternating qty

Average value:-

It is the average of waveforms values over a period of time

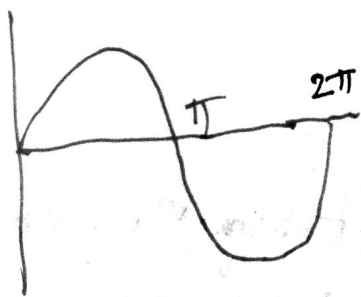
Time interval over which net area is ~~computed~~ computed is the period T of waveform

$$\text{Average value} = \frac{\text{Total area under curve for time } T}{\text{Time } T}$$

$$\text{Avg value} = \frac{\text{area under wave}}{\text{length of wave}}$$

We'll get zero if we consider full cycle because the +ve & -ve get cancelled so we only consider half cycle

$$\text{Area of half cycle} = \int_0^{\pi} i \, d\theta$$



$$= \int_0^{\pi} I_{\max} \sin \theta \, d\theta$$

$$= I_{\max} [-\cos \theta]_0^{\pi} = 2 I_{\max}$$

~~$i_1 = I_{\max} \sin \omega t$ is valid when wave form passes via origin~~

~~$i_2 = I_{\max} \sin(\omega t \pm \theta)$ is valid when wave form isn't passing via origin~~

~~Area~~

Avg value = $\frac{\text{Area of half cycle}}{\text{Base length of half cycle}} = \frac{2 I_{\max}}{\pi}$

$$I_{\text{av}} = 0.637 I_{\max}$$

$$V_{\text{av}} = 0.637 V_{\max}$$

Average value is calculated based on charge transfer

Half cycle average value of A_c is the value of DC which would send the same amount of charge via a circuit for half the time period of A_c as is sent by a_c through same circuit in the same time.

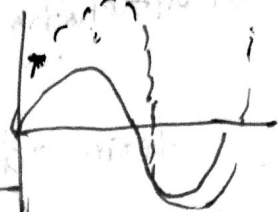
RMS or Effective value

It is steady current (DC) when flowing via given resistance for a given time produces the same amount of heat produced by alternating current when flowing through the same resistance for the same time.

(63)
RMS is based on heat transfer

Root mean square is full form of RMS

$$\text{Ar. of half cyc Sq wave} = \frac{\pi I_{\max}^2}{2}$$



$$I_{\text{rms}} = \sqrt{\frac{\text{Ar. of half cycle Squared wave}}{\text{half cycle base}}}$$

$$= \sqrt{\frac{\pi I_m^2 / 2}{\pi}} = \frac{I_{\max}}{\sqrt{2}} = 0.707 I_{\max}$$

$$I_{\text{rms}} = 0.707 I_{\max}$$

$$V_{\text{rms}} = 0.707 V_{\max}$$

ambs

(69)

Form factor

It is the ratio of rms value to the avg value of an alternating qty

$$\text{form factor} = \frac{\text{RMS value}}{\text{Average value}}$$

for sinusoidal v or I, form factor is 1.11

Peak factor

The ratio of maximum value to the rms value of an alternating quantity

$$\text{Peak factor} = \frac{\text{Max value}}{\text{RMS value}}$$

value of peak depends on waveform

for Av or Ac in sin = 1.414

Bg: Find rms, avg & form factor of a half wave rectified voltage

A)
$$I_{av} = \frac{\text{Area of one cycle}}{\text{Full cycle base}} = \frac{2 I_m \pi}{2\pi} = \frac{I_m}{\pi}$$

$$I_{rms} = \left[\frac{\text{Area of squared wave over one cycle}}{\text{Full cycle base}} \right]^{1/2}$$

(70)

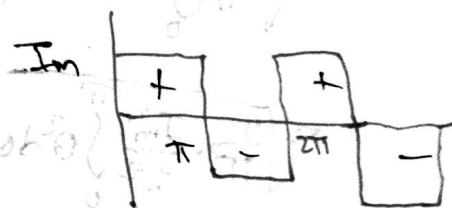
$$= \sqrt{\frac{\frac{\pi I_m^2}{2}}{2\pi}}$$

$$= \frac{I_m}{2}$$

$$I_{rms} = \int^{\pi}$$

Ex: Find rms & avg of Square wave shown in figure

I_{avg} for half cycle



$$I_{average} = \frac{\text{Area under the half cycle}}{\pi}$$

$$= \frac{I_{max} \pi}{\pi} = I_{max}$$

$$I_{rms} = \sqrt{\frac{\int_0^{\pi} i^2 d\theta}{\pi}}$$

$$= \sqrt{\frac{\int_0^{\pi} I_m^2 d\theta}{\pi}}$$

$$= I_m \sqrt{\frac{\pi - 0}{\pi}}$$

$$= I_m$$

For Square wave

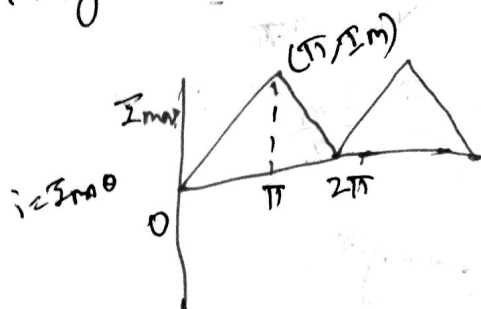
$$I_{avg} = I_{rms} = I_m$$

Peak factor = form factor = 1

Q7) Find avg & rms for triangular wave

$$I_{avg} = \frac{\frac{1}{2} \times 2\pi \times I_m}{2\pi}$$

$$= \frac{I_m}{2}$$



$$I_{rms} = \sqrt{\frac{1}{\pi} \int_0^{\pi} i^2 d\theta} = \sqrt{\frac{1}{\pi} \int_0^{\pi} \frac{I_m^2}{\pi^2} \theta^2 d\theta}$$

$$= \sqrt{\frac{1}{\pi} \times \frac{I_m^2}{\pi^2} \int_0^{\pi} \theta^2 d\theta}$$

$$= \sqrt{\frac{I_m^2}{\pi^3} \left[\frac{\theta^3}{3} \right]_0^{\pi}}$$

$$= \frac{I_m}{\sqrt{3}}$$

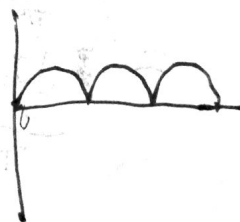
Q8) Find avg & rms for full wave rectified waveform

$$I_{avg} = \frac{\text{Area under curve}}{\text{Base length}}$$

$$= \frac{\int_0^{\pi} I_m \sin \theta d\theta}{\pi}$$

$$= \frac{I_m \int_0^{\pi} \cos \theta d\theta}{\pi}$$

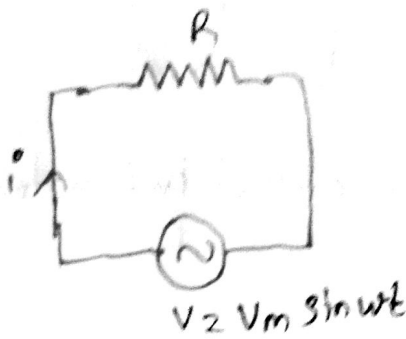
$$= \frac{I_m (2)}{\pi} = \frac{2I_m}{\pi}$$



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(73)

AC through Resistor



$$i = \frac{V}{R}$$

$$i = i_R$$

$$i = \frac{V_m \sin \omega t}{R}$$

$$I_m = \frac{V_m}{R}$$

There is no phase diff b/w current & voltage in case of resistor

Small $p \rightarrow$ Instantaneous power = $V i$

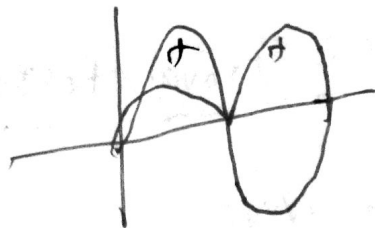
$$= V_m \sin \omega t \times I_m \sin \omega t$$

$$= V_m I_m \sin^2 \omega t$$

$$= V_m I_m \frac{(1 - \cos 2\omega t)}{2}$$

$$= V_m \frac{I_m}{2} - \frac{V_m I_m}{2} \cos 2\omega t$$

Instantaneous power has
2 components, fixed comp



Avg value of AC power consumed by resistor

$$P = \frac{V_m I_m}{2}$$

$$= \frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}}$$

$$P = V_{rms} I_{rms}$$

$$P = \sqrt{2}$$

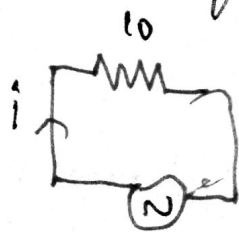
Eg:- A c circuit consisting of pure resistance 10Ω and is connected across an ac supply of $230V$ $50Hz$.

Calculate

i) current ii) power consumed iii) equations for

$$V = V_{rms} = 230V, f = 50Hz, R = 10\Omega$$

$$I_{rms} = \frac{V_{rms}}{R} = \frac{230}{10} = 23A$$



voltage & current

(75)

$$P = V_{rms} I_{rms}$$

$$= 23 \times 280$$

$$= 6290 \text{ W}$$

$$V_m = \sqrt{2} V = \sqrt{2} \times 230 = 325.27 \text{ V}$$

$$I_m = \sqrt{2} I = \sqrt{2} \times 23 = 32.52 \text{ A}$$

$$\omega = 2\pi f = 2\pi \times 50 = 314 \text{ rad/s}$$

Equations of voltage and current are:

$$v = 325.27 \sin 314t \quad i = 32.52 \sin 314t$$

Eg- Inductor through which AC flows



$$v = V_m \sin \omega t$$

We use a mH inductor

When AC flows via inductor, a back emf E_L is induced due to inductance of coil

Back emf at every instant opposes change in current via coil. Because of lack of resistance, applied voltage has to overcome back emf only

$$E_L = L \frac{di}{dt}$$

$$E_L = V = V_m \sin \omega t$$

$$2) L \frac{di}{dt} = V_m \sin \omega t$$

$$\frac{di}{dt} = \frac{V_m}{L} \sin \omega t$$

$$= \int i = \int \frac{V_m}{L} \sin \omega t$$

$$= \frac{V_m}{\omega L} (-\cos \omega t)$$

$$= \frac{V_m}{\omega L} \sin(\omega t - \frac{\pi}{2})$$

There is a phase difference between ~~phase~~ current
 Current lags behind voltage by 90° * Voltage
 i maximum when $\sin(\omega t - \frac{\pi}{2})$ is unity

$$I_m = V_m / \omega L$$

$$i = I_m \sin(\omega t - \frac{\pi}{2})$$

$$X_L = \omega L$$

$X_L \rightarrow$ Inductive reactance (Ω)

Ohms law for Inductor:-

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$$\Rightarrow I_m = \frac{V_m}{X_L}$$

$$\frac{I_m}{\sqrt{2}} = \frac{V_m/\sqrt{2}}{X_L}$$

$$I = \frac{V_L}{X_L}$$

$$X_L = \omega L = 2\pi fL$$

Power

Instantaneous power $p = v i$

$$= V_m \sin \omega t \times I_m \sin(\omega t - \frac{\pi}{2})$$

$$= -\frac{V_m I_m}{2} \sin \omega t$$

$$\text{Avg Power} = 0$$

$\therefore$ Power consumed by pure inductor is zero

Eg:- A pure inductive coil allows a current of 10A to flow from a 230V 50Hz supply.

Find

- i) Inductive reactance
- ii) ~~Inductive~~ Inductance of coil
- iii) Power absorbed

Write down the equations for voltage & current

4) i) $I = V/X_L$

$$X_L = V/I$$

$$= \frac{230}{10}$$

$$= 23 \Omega$$

ii) $X_L = 2\pi fL$

$$\therefore L = \frac{X_L}{2\pi f} = \frac{23}{2\pi \times 50} = 0.073 \text{ H}$$

iii) Power absorbed is

$$V_m = 230 \times \sqrt{2} = 325.27 \text{ V}$$

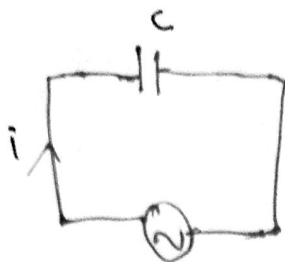
$$I_m = 10 \times \sqrt{2} = 14.14 \text{ A}$$

$$\omega = 2\pi \times 50 = 314 \text{ rad/s}$$

$$V = 325.27 \sin 314t$$

$$i = 14.14 \sin(314t - 90^\circ)$$

Alternating current via capacitance



When alt voltage is applied on capacitor, the current gets stored and flows out of the capacitor and produces AC

Charge on capacitor, $q = CV = C V_m \sin \omega t$

$$\text{Circuit current } i = \frac{dq}{dt} = \frac{d(C V_m \sin \omega t)}{dt} = \omega C V_m \cos \omega t$$

$$i = \omega C V_m \sin(\omega t + \frac{\pi}{2})$$

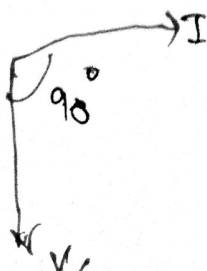
Value of i is max when $(\sin \omega t + 90^\circ)$ is unity

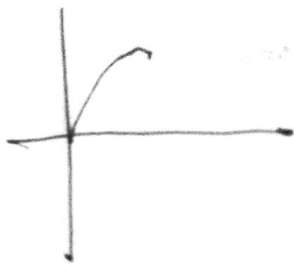
$$I_m = \omega C V_m$$

Substituting $\omega C V_m = I_m$

$$\text{we get } i = I_m (\sin \omega t + 90^\circ)$$

Phase angle: current leads voltage by 90°





Power!

$$P = v i = V_m I_m \sin \omega t \cos \omega t$$

$$P = \frac{V_m I_m}{2} \sin 2\omega t$$

Avg P = Average of P over one cycle

$$= \frac{1}{2\pi} \int_0^{2\pi} \frac{V_m I_m}{2} \sin 2\omega t d(\omega t) = 0$$

Power absorbed by ~~the~~ ~~capacitor~~ ~~is~~

Power capacitor is zero

$$I_m = \frac{V_m}{X_c} \quad \left| \quad X_c = \frac{1}{\omega C} \quad X_c \rightarrow \text{capacitive reactance} \right.$$

Eg:- A $318 \mu\text{F}$ capacitor is connected across 230V , 50Hz system. Determine (i) capacitive reactance

(ii) rms value of current

(iii) equations for voltage & current

$$A) (i) X_C = \frac{1}{2\pi fC} = \frac{10^6}{2\pi \times 50 \times 318} = 10 \Omega$$

$$(ii) I_{\text{rms}} = \frac{V}{X_C} = \frac{230}{10} = 23 \text{ A}$$

$$(iii) V_m = 230 \times \sqrt{2} = 325.27 \text{ V}$$

$$I_m = \sqrt{2} \times 23 = 32.53 \text{ A}$$

$$\omega = 2\pi \times 50 = 314 \text{ rad/s}$$

Eq. for voltage

$$V = 325.27 \sin 314t$$

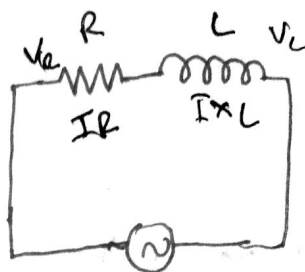
$$I = 32.53 \sin(314t - 90^\circ)$$

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82

AC through R-L Series

Consider a Resistor & Inductor in series with AC voltage



We use RMS here

Let V represent V_{rms}

I represent I_{rms} flowing via circuit

$X_L \rightarrow$ opposition offered by Inductor

Let $V_R \rightarrow$ voltage drop across resistor

$V_L \rightarrow$ voltage drop across inductor

Wkt

Current & voltage are in phase in case of resistor
Current is lagging in inductor

Current is taken as reference as it is same in both components

Phasor representation of R & L

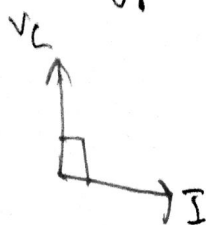
$\rightarrow I$

$\rightarrow V_R$

$\rightarrow I$
 $\uparrow V_L$

or

$V_R = IR$



$V_L = IX_L$

We can also apply KVL for vectors

$$\vec{V} = \vec{V}_R + \vec{V}_L$$

$$= \vec{I}R + j\vec{I}X_L$$

$j \rightarrow$ Indicates rotation of vector by 90° in clockwise direction

$j \rightarrow$ Indicates rotation of vector by 90° in anticlockwise direction

$$\Rightarrow \vec{I}(R + jX_L)$$

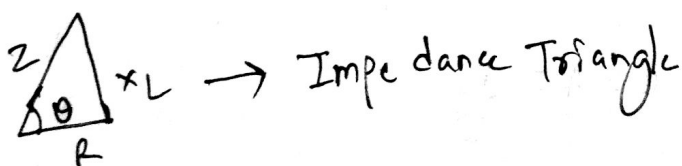
$$\Rightarrow \frac{\vec{V}}{\vec{I}} = R + jX_L \quad (\because R + jX_L = Z)$$

$$\frac{\vec{V}}{\vec{I}} = Z$$

$Z \rightarrow$ Impedance (Ω)

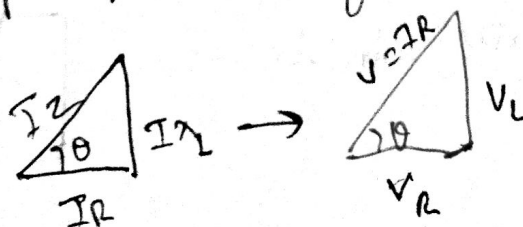
$$|Z| = \sqrt{R^2 + X_L^2}$$

$$\theta = \tan^{-1}\left(\frac{X_L}{R}\right)$$



$Z \rightarrow$ opposition offered by series RL for the flow of AC current

We can represent it in a triangle



$$|V| = \sqrt{V_R^2 + V_L^2}$$

Both current & v will have a phase difference (ϕ) which is between $0 - 90^\circ$

We can find the angle by

$$\theta = \tan^{-1}\left(\frac{X_L}{R}\right) = \tan^{-1}\left(\frac{2\pi f L}{R}\right)$$

Instantaneous Power

$$P = v i = V_m \sin \omega t \times I_m \sin(\omega t - \phi)$$

$$\text{Avg } P = \frac{V_m I_m}{2} \cos \phi = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}} \times \cos \phi$$

$$P = \cancel{V_m} V_{rms} I_{rms} \cos \phi$$

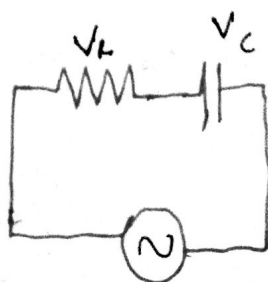
$\cos \phi \rightarrow$ Power factor

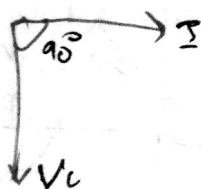
$\downarrow$
cosine of phase angle b/w $\vec{V}$ & $\vec{I}$

$$\cos \phi = \frac{R}{Z}$$

Ac through RC series circuit

In this resistor & capacitor are connected in series with Ac voltage



Phasor diagram $\rightarrow I$ $\rightarrow V_R$ 

In case of capacitor current leads voltage by 90°

Applying KVL

$$\vec{V} = \vec{V}_R + \vec{V}_C$$

$$= IR + IX_C$$

$$= IR - jIX_C \quad (\because \text{vector rotates by } 90^\circ \text{ clockwise})$$

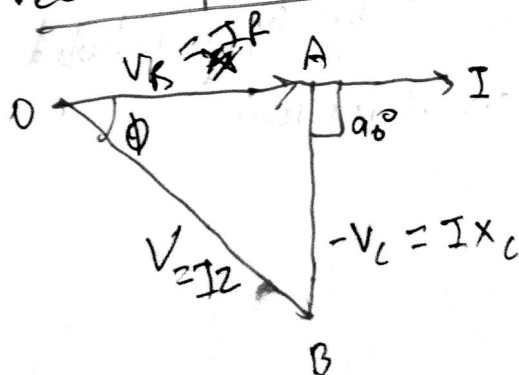
$$= I(R - jX_C)$$

$$Z = \frac{V}{I} = R - jX_C$$

$$\vec{Z} = R - jX_C$$

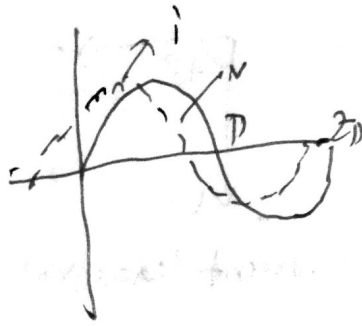
$$|Z| = \sqrt{R^2 + X_C^2}$$

$$\theta = \tan^{-1}\left(\frac{X_C}{R}\right) \quad (\theta \text{ is negative})$$

Vector representation

ϕ is angle between $\vec{V}$ & $\vec{I}$

$$\Rightarrow \tan \phi = \frac{-V_C}{V_R} = -\frac{IX_C}{IR} = -\frac{X_C}{R}$$



current is leading w.r.t voltage ~~by~~ ϕ
in RC

$\phi \rightarrow$ between $0^\circ - 90^\circ$

$$\Rightarrow \phi = \tan^{-1} \left(\frac{1}{\omega CR} \right)$$

Power factor

$$\cos \phi = \frac{R}{Z}$$

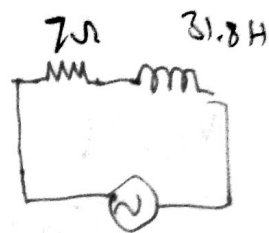
Ex: A coil having resistance 7Ω and inductance of $31.8mH$ is connected to $230V$ $50Hz$ supply. Calculate

- (i) ~~power consumed~~ current in circuit
- (ii) phase angle
- (iii) Power factor
- (iv) Power consumed
- (v) Voltage drop across resistor or inductor

(82)

$$V_{rms} = 230V$$

$$f = 50Hz$$



✱

$$X_L = 2\pi fL = 2 \times \pi \times 50 \times 31.8$$

$$= 100\pi \times 31.8 \times 10^{-3}$$

$$= 10\Omega$$

$$Z = \sqrt{R^2 + X_L^2}$$

$$= \sqrt{7^2 + 31.8^2}$$

$$= \sqrt{149}$$

$$= 12.2\Omega$$

$$i = \frac{V}{Z}$$

$$= \frac{230}{12.2}$$

$$= 18.8A \quad \text{--- (i)}$$

$$\theta = \tan^{-1}\left(\frac{X_L}{R}\right)$$

$$= \tan^{-1}\left(\frac{10}{7}\right)$$

$$= 55.007^\circ$$

~~cos φ~~

$$\text{Power factor} = \cos \phi =$$

$$= \cos 55^\circ$$

$$= 0.57$$

$$V_R = IR$$

$$= 18.8 \times 7$$

$$= 131.6$$

$$V_L = IX_L = 18.8 \times 10$$

$$= 188$$

$$P = VI \cos \phi$$

$$= 230 \times 18.8 \times 0.57$$

$$= 2464 \text{ W}$$

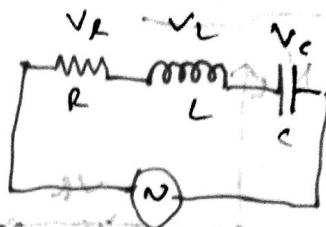
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(89)

AC through RLC

$$V = V_{rms}$$

I starts flowing via circuit



Let V_R be voltage drop across resistor

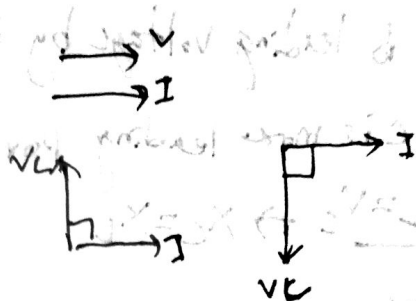
V_L be voltage drop across inductor

V_C be voltage drop across capacitor

$$V_R = IR$$

$$V_L = IX_L$$

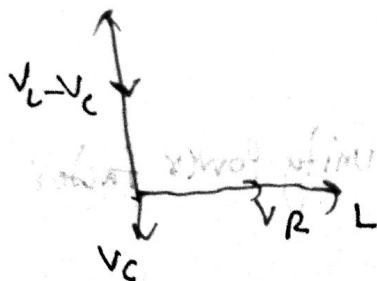
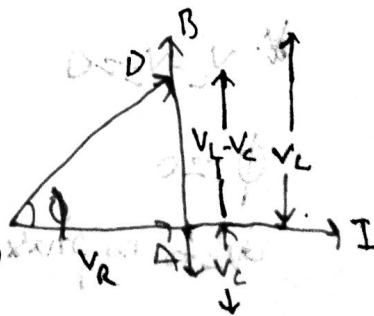
$$V_C = IX_C$$



Let us take current is common for all as it is same for all elements

V_L and V_C are in phase opposition therefore we have to take net value

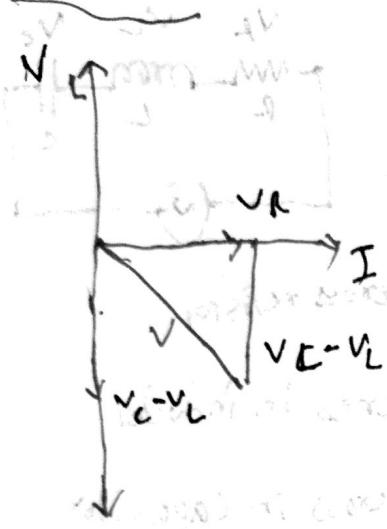
$$\text{Let } V_C < V_L \rightarrow X_C < X_L$$



I is lagging wrt voltage by ϕ

Since L is more, lagging effect of power factor takes place

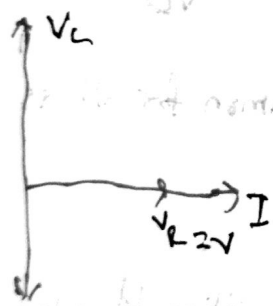
let $V_C > V_L \rightarrow X_C > X_L$



I is leading voltage by ϕ

Since circuit is more leading power factor takes place

let $V_L = V_C \rightarrow X_C = X_L$



$$V_L - V_C = 0$$

$$\phi = 0$$

due to no phase difference

When $\cos \phi = 1$, it is called unity power factor

when $X_L = X_C$ is ∞ , it behaves like RL circuit

when $X_L - X_C$ is $-ve$, it behaves like RC circuit

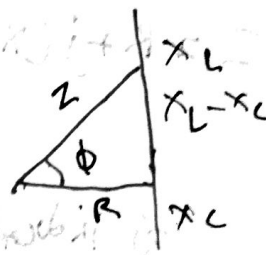
when $X_L - X_C = 0$, it behaves like pure resistive circuit

$$\vec{V} = \vec{V}_R + j\vec{V}_L - j\vec{V}_C$$
$$= IR + jIX_L - jIX_C$$

$$V = I(R + jX_L - jX_C)$$

$$V = I(R + j(X_L - X_C))$$

$$Z = \frac{V}{I} = R + j(X_L - X_C)$$



$$|Z| = \sqrt{R^2 + (X_L - X_C)^2}$$

$$\theta = \tan^{-1} \left(\frac{X_L - X_C}{R} \right) \rightarrow \theta \text{ is } +ve$$

$$\theta = \tan^{-1} \left(\frac{X_C - X_L}{R} \right) \rightarrow \theta \text{ is } -ve$$

Eg:- A 230V, 50Hz ac supply is applied to a coil of 0.06H inductance and 2.5Ω resistance connected in series with $6.8\mu F$ capacitor. Calculate i) impedance ii) current iii) phase angle between current and voltage iv) power factor v) power consumed (Active) & Reactive power & apparent power

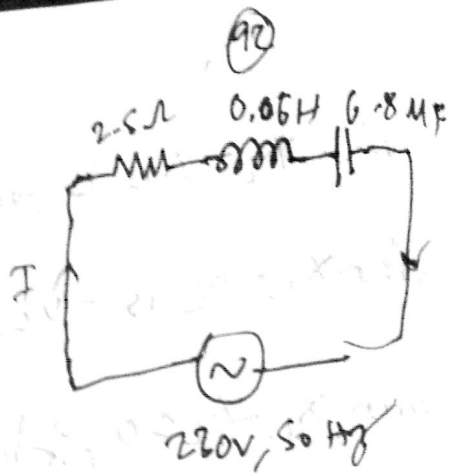
given

$$R = 2.5 \Omega$$

$$C = 6.8 \mu F$$

$$L = 0.06 H$$

Applied voltage 230V, 50 Hz



$$X_L = 2\pi fL = 2\pi \times 50 \times 0.06 = 18.85 \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{314 \times 6.8 \times 10^{-6}} = 468 \Omega$$

Here $X_C > X_L$

$$Z = R + j(X_L - X_C) = 2.5 + j(18.85 - 468) = 2.5 - j449.15$$

$-j$ indicates that it is RC-circuit

$$= 449.15 \angle 89.6$$

$$\vec{I} = \frac{\vec{V}_L}{\vec{Z} \angle 0^\circ}$$

$$= \frac{230 \angle 0^\circ}{449.156 \angle -89.6^\circ}$$

$$= 0.512 \angle 0 - (-89.6)$$

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$$0.512 \angle 89.6$$

I is leading V by 89.6

$$\phi = 89.6^\circ$$

$$P_f = \cos \phi = \cos 89.6^\circ = 0.006 \text{ lead}$$

Active power $P = VI \cos \phi$

$$= 230 \times 0.512 \times 0.006$$

$$= 0.706 \text{ W}$$

Reactive power $Q = VI \sin \phi$

$$= 230 \times 0.512 \times \sin 89.6$$

$$= 117 \text{ VAR}$$

Apparent power $S = VI$

$$= 230 \times 0.512$$

$$= 117.76 \text{ VA}$$

Q) Resistance R , $L = 0.01 \text{ H}$, C are connected in series. When Alternating voltage $V = 400 \sin(3000t - 20^\circ)$ is applied to the series combination, current flowing is $10\sqrt{2} \sin(3000t - 65^\circ)$. Find R & C

A) Current is lagging

∴ it is RL series circuit

(94)

$$\phi = 65^\circ - 20^\circ = 45^\circ \text{ lag}$$

$$X_L = \omega L = 3000 \times 0.01 = 30 \Omega$$

$$\tan 45^\circ = \frac{X}{R} \therefore X = R$$

$$Z = \frac{V_m}{I_m} = \frac{400}{10\sqrt{2}} = 28.3 \Omega$$

$$Z^2 = R^2 + X^2 = R^2 + R^2 = 2R^2$$

$$R = \frac{Z}{\sqrt{2}} = \frac{28.3}{\sqrt{2}} = 20 \Omega$$

$$X = X_L - X_C$$

$$\therefore X_C = X_L - X$$

$$= 30 - 20 = 10 \Omega$$

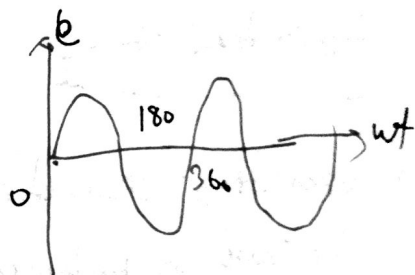
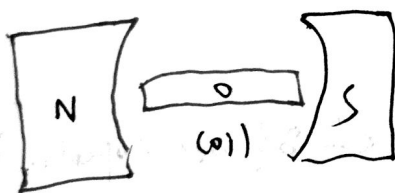
$$C = \frac{1}{\omega X_C} = \frac{1}{3000 \times 10} = 33.3 \times 10^{-6} \text{ F}$$

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(95)

3- ϕ AC circuit

- A single phase generator has only one armature winding
- If there are 2 or more separate windings, it is called poly phase generators
- Electrical displacement b/w windings depends on the no of phases
- winding is also called coil
- Single phase generates only 1 EMF

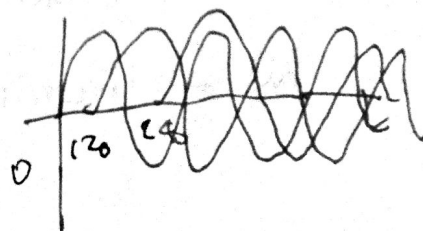
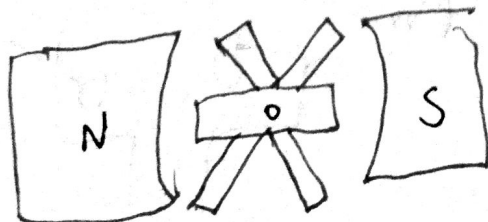


- Two coils generate 2 EMF, the two coils are similar

$$\Rightarrow \text{EMF in coil 1} = \text{EMF in coil 2}$$

- Magnitude will be similar but there is a phase difference of 90°

- 3 coils generate 3 EMF



- The terminals are 120 degrees apart

Equations of 3 ϕ EMF

$$e_{a_1 a_2} = E_m \sin \omega t$$

$$e_{b_1 b_2} = E_m \sin(\omega t - 120^\circ)$$

$$e_{c_1 c_2} = E_m \sin(\omega t - 240^\circ)$$

Three coils are identical & have same ω

Advantages of 3 ϕ

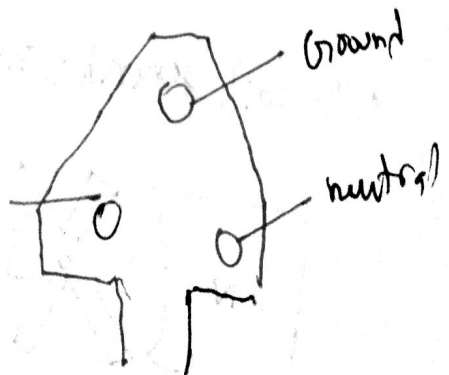
- operating characteristics of 3 ϕ are superior to 1 ϕ because in balanced 3 ϕ , power is constant
- Output of 3 ϕ is more than 1 ϕ
- 3- ϕ motors are smaller and less expensive than 1- ϕ motors because less material required for manufacture

Black $\rightarrow$ neutral wire

Green $\rightarrow$ Ground

Red $\rightarrow$ live wire

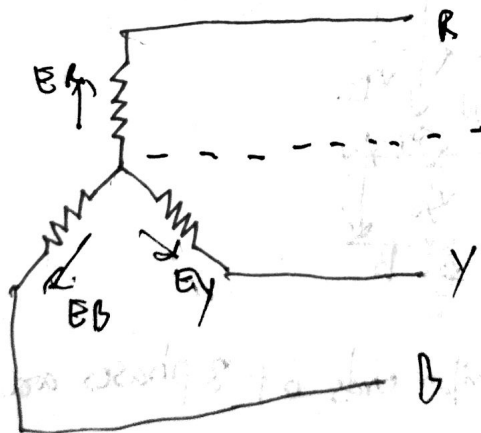
five



Characteristics of 3 ϕ motors

- They are cheap
- They are silent
- They are self starting motors
- ~~They~~ We can adjust the speed
- High torque
- Higher power output
- Power is produced & transmitted in 3 ϕ system

Interconnection of 3 ϕ



Connecting 3 3ϕ 's is difficult & wire consuming
So we use Star connection

It is formed by interconnecting similar ends

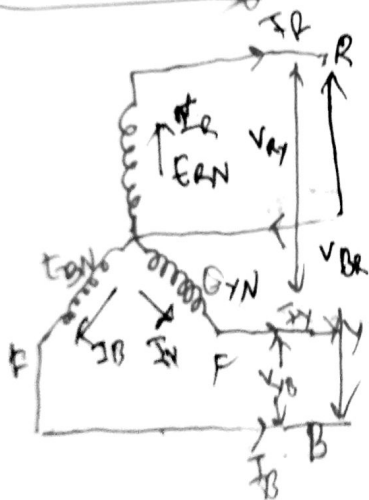
It can be used for 1 ϕ & 3 ϕ



This is delta connection where dissimilar ends are connected

It can be only used for 3 ϕ system.

Star connection system



In this, similar ends of 3 phases are connected to form star connection

The conductors are R, Y & B

E_{RN} = Voltage b/w R and N

E_{YN} = Voltage b/w Y & N

E_{BN} = Voltage b/w B & N

(9)
 E_{RN}, E_{YN}, E_{BN} are called 1- ϕ voltages

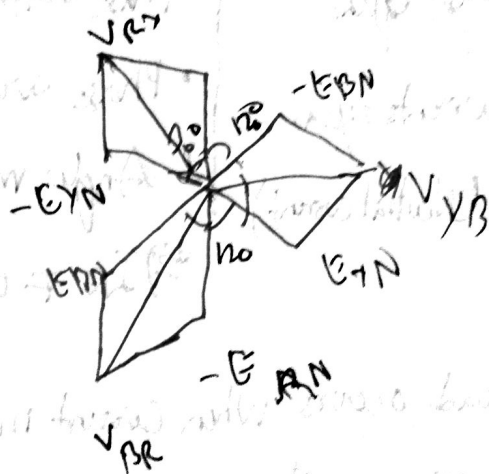
V_{RY}, V_{BR}, V_{YB} are called line voltages

I_R, I_Y, I_B are winding currents or ϕ currents

line current $\rightarrow$ current flowing via lines

In star connection, ~~each~~ line current & phase currents are same because each line is connected to only one phase

Phase voltages & line voltages are different but line currents and phase currents are same in case of star connection

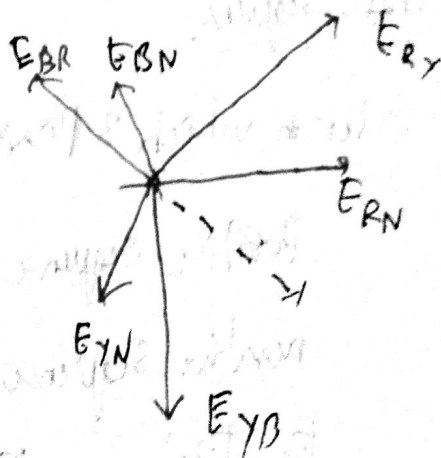


$$I_{\phi} = I_{line}$$

$$V_{\phi} \neq V_{line}$$

$$\begin{aligned} \vec{E}_{RY} &= \vec{E}_R - \vec{E}_Y \\ &= \vec{E}_{RN} - \vec{E}_{YN} \end{aligned}$$

$$\vec{E}_{YB} = \dots$$



$$V_{BR} = V_{BY} = V_{RY} = \sqrt{3} E_{ph}$$

$\Rightarrow$ line voltage $= \sqrt{3} \times$ phase voltage

line current $=$ phase current

Total power of balanced load in each phase:

$$P = \sqrt{3} V_L I_L \cos \phi$$

Balanced	Unbalanced
• phase voltages equal • line phase currents equal $\Rightarrow I_N = 0$ (Neutral current)	• Phase voltages may be unequal • Phase current may be unequal • Angles may not be 120° $\Rightarrow I_N \neq 0$

Unbalanced load occurs when current mismatch occurs and neutral wire will carry current

Phase sequence

order in which 3 phases attain their max values

Positive sequence $\rightarrow$ counter clockwise

Negative sequence $\rightarrow$ clockwise

$$E_R = E \angle 0^\circ$$

$$E_Y = E \angle -120^\circ \quad E_B = E \angle 120^\circ$$

(101)

Numerical Problems in star connection

Egr Phasor voltages of star connected alternator are $E_R = 231 \angle 0^\circ$, $E_Y = 231 \angle -120^\circ$ & $E_B = 231 \angle 120^\circ$ V. What is phase sequence of the system? Compute line voltages E_{RY} & E_{YB}

A) Given

$$E_R = 231 \angle 0^\circ, E_B = 231 \angle +120^\circ \rightarrow 231 \angle -240^\circ$$

Here phase sequence is RYB

$$E_R = 231 \angle 0^\circ$$

$$E_Y = 231 \angle -120^\circ$$

$$E_B = 231 \angle -240^\circ$$

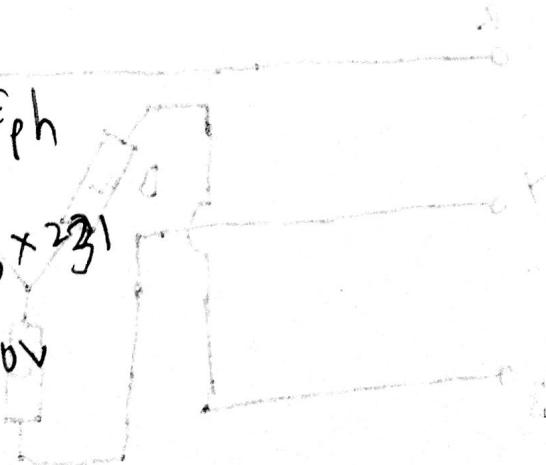
phase difference is 120° , $\therefore$ it is balanced

~~E_{ph}~~

$$E_{line} = \sqrt{3} E_{ph}$$

$$= \sqrt{3} \times 231$$

$$= 400 \text{ V}$$



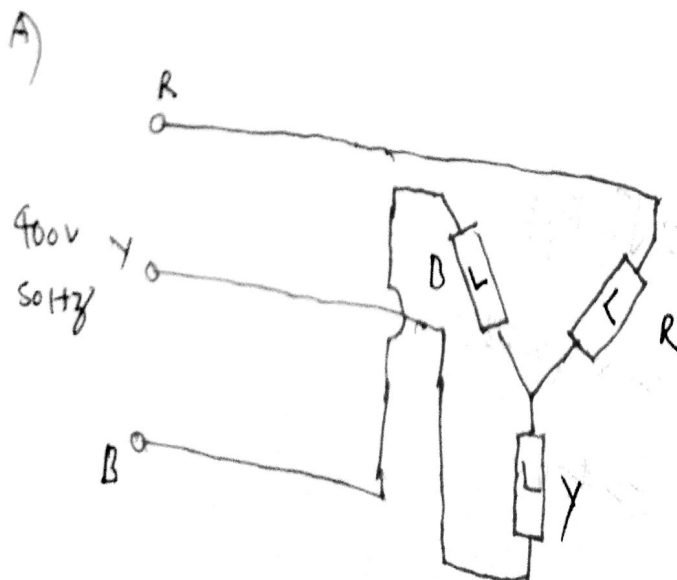
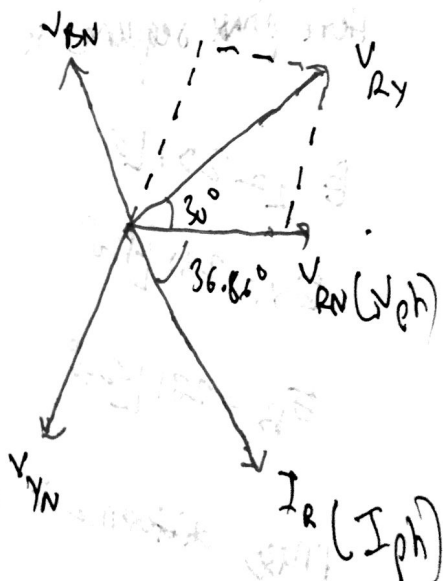
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(102)

Ex: 8 phase Star connected load when supplied from 400V, 50 Hz source takes a line current of 10A at 66.86° wrt line voltage.

Calculate

- impedance parameters
- power factor & active power consumed



(108)

$$(rms)_{400} = \text{line voltage} - V_L$$

$$V_{ph} = \frac{V_L}{\sqrt{3}}$$

$$= \frac{400}{\sqrt{3}} = 231$$

$$V_R = 231 \angle 0^\circ$$

$$V_Y = 231 \angle -120^\circ$$

$$V_B = 231 \angle -240^\circ$$

Angle difference b/w 66.86°

Power factor $\cos \phi \rightarrow$ angle b/w V_{ph} & I_{ph}

$$P \rightarrow V_{ph} \cos \phi I_{ph}$$

$$\phi \rightarrow 36.86^\circ$$

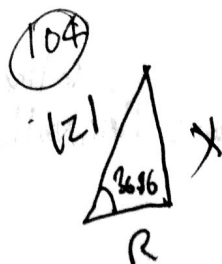
Power factor $\cos \phi = \cos 36.86^\circ = 0.8 \text{ lag}$

Now we need to calculate power factor

$$Z_{ph} = \frac{V_{ph}}{I_{ph}} = \frac{231}{10} = 23.1 \Omega$$

$$R = Z \cos \phi$$

$$X_L = Z \sin \phi \quad (X_L \text{ because it's lagging})$$



$$R = Z \cos \phi$$

$$= 28.1 \times 0.8$$

$$= 18.48 \Omega$$

$$X_L = Z \sin \phi$$

$$= 28.1 \times 0.59$$

$$= 13.85 \Omega$$

$$P_{3\phi} = \sqrt{3} V_L I_L \cos \phi = \sqrt{3} \times 400 \times 10 \times 0.8$$

$$= 5544 \text{ W}$$

$$Q_{3\phi} = \sqrt{3} V_L I_L \sin \phi = \sqrt{3} \times 400 \times 10 \times 0.59$$

$$= 4087 \text{ W}$$

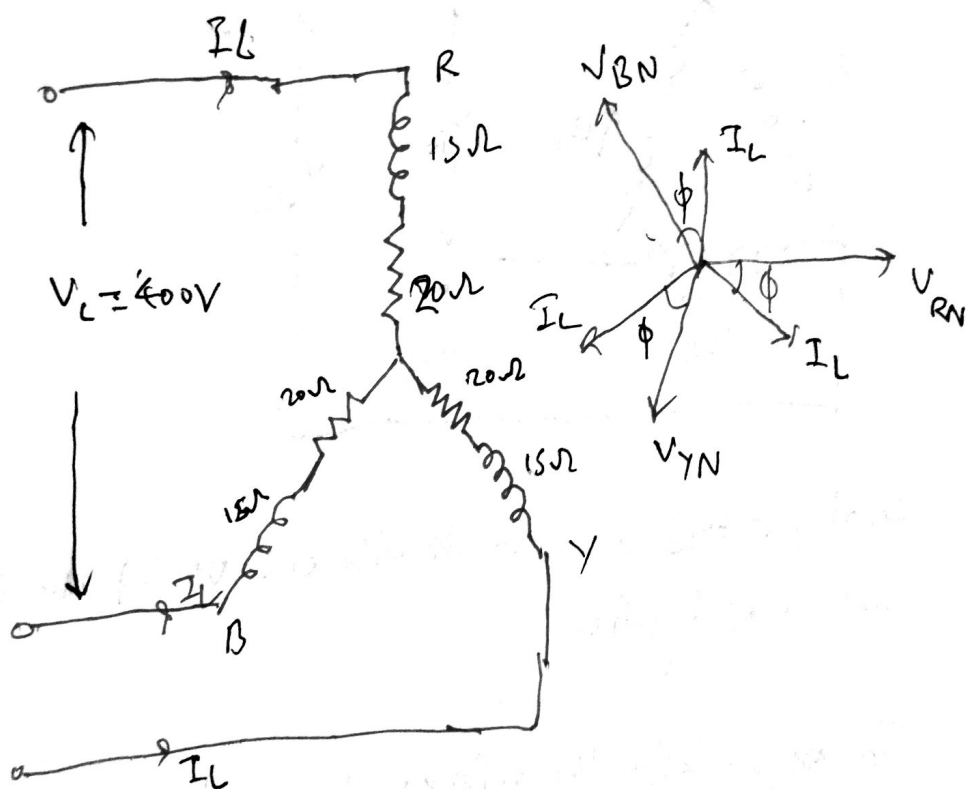
$$S_{3\phi} =$$

(105)

Ex: 3 coils each having ~~20~~ 20Ω and X_L of 15Ω are connected in star to $400V$ supply.

Calculate

- i) line current
- ii) power factor
- iii) power supplied



$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 231V$$

$$Z_{ph} = \sqrt{20^2 + 15^2} = 25\Omega$$

$$I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{231}{25} = 9.24A$$

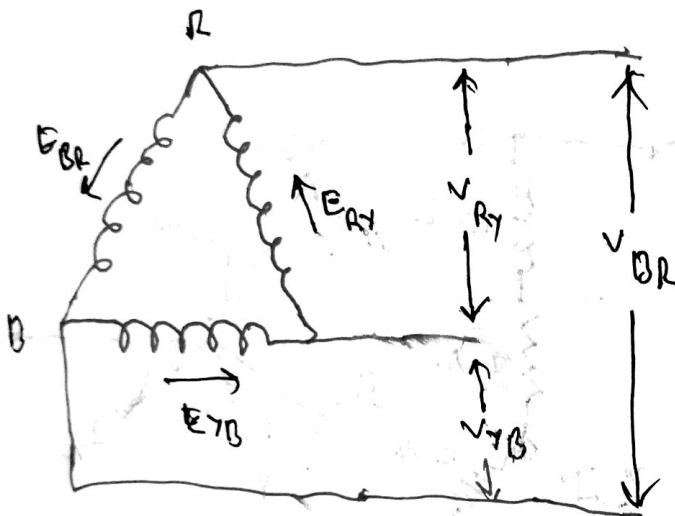
$$I_L = I_{ph} = 9.24A$$

$$\cos \phi = \frac{20}{25} = 0.8 \text{ lag}$$

$$P = \sqrt{3} V_L I_L \cos \phi$$

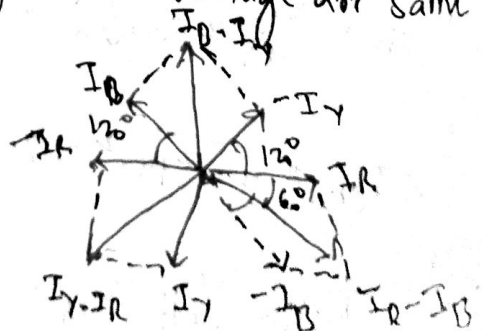
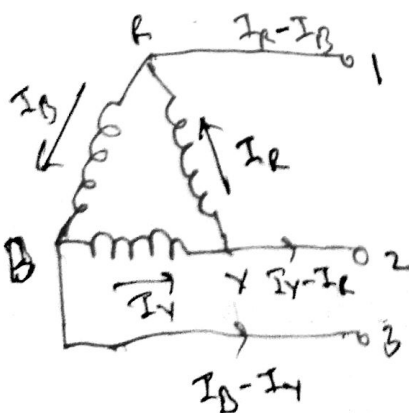
$$= \sqrt{3} \times 400 \times 9.24 \times 0.8 = 5121 \text{ W}$$

Delta connected system or mesh connected system



In this method, we join dissimilar ends of 3 ϕ windings are joined together

In case of delta, line voltage & phase voltage are same



line voltages of phase

$$\bar{I}_1 = \bar{I}_R - \bar{I}_D$$

$$= \bar{I}_R + (-\bar{I}_D)$$

$$\bar{I}_2 = \bar{I}_Y - \bar{I}_R$$

$$= \bar{I}_Y + (-\bar{I}_R)$$

$$\bar{I}_3 = \bar{I}_B - \bar{I}_Y$$

$$= \bar{I}_B + (-\bar{I}_Y)$$

$$I_1 = \sqrt{3} I_{ph}$$

$$|I_1| = |I_2| = |I_3|$$

- In delta, line current is not equal to phase current.
- Line currents are 30° lagging behind I_{ph} .
- Magnitudes of line currents are equal but displaced 120° from one another.
- Total power in phase.

$$P = 3 \times \text{Power per phase}$$

$$= 3 \times V_{ph} I_{ph} \cos \phi$$

$$P = \sqrt{3} V_L I_L \cos \phi$$

This formula applies only for balanced system

If the system is unbalanced then we have to use

$$P_{3\phi} = P_a + P_b + P_c$$

Problems on delta

Ex: A 3ϕ Δ -connected alternator drives a balanced 3ϕ load whose phase current is 10A in magnitude. At the time, when $I_a = 10\angle 30^\circ$ A. Determine the following Phase Sequence of abc.

i) Polar expressions for I_b & I_c

ii) Polar expressions for three line currents

A) $I_a = 10\angle 30^\circ$

$$I_b = 10\angle -90^\circ$$

$$I_c = 10\angle -210^\circ$$

$$I_L = \sqrt{3} I_{ph} = \sqrt{3} \times 10 = 17.32 \text{ A}$$

$$I_L = 17.32\angle 30^\circ - 30^\circ$$

$$= 17.32\angle 0^\circ$$

$$I_{L2} = 17.32 \angle 0 - 120^\circ$$

$$= 17.32 \angle -120^\circ$$

$$I_{L3} = 17.32 \angle 0 - 240^\circ$$

$$= 17.32 \angle -240^\circ$$

Eg:

3 similar coils each having a resistance of 5Ω and L of $0.02H$ are connected in delta to $440V$ 3ϕ supply. Calculate the line current & power absorbed

A) Reactance of coil $X_L = 2\pi fL$

$$= 2\pi \times 50 \times 0.02 = 6.28\Omega$$

$$Z_{ph} = \sqrt{R^2 + X_L^2}$$

$$= \sqrt{5^2 + 6.28^2} = 8.05\Omega$$

Power factor $\cos \phi = \frac{R_{ph}}{Z_{ph}} = \frac{5}{8.05} = 0.622 \text{ lag}$

Phase voltage, $V_{ph} = V_L = 440V$

Phase current or $I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{440}{8.05} = 54.6A$

$$\text{line current } I_L = \sqrt{3} I_{ph} = \sqrt{3} \times 54.6 = 94.8 \text{ A}$$

$$\text{Power absorbed } P = \sqrt{3} V_L I_L \cos \phi$$

$$= \sqrt{3} \times 440 \times 94.8 \times 0.622$$

$$= 45000 \text{ W}$$

Star connection is used where voltage requirement is more

Delta connection is used when current requirement is more

Ex:- A balanced delta connected load takes a line current of 18 A at power factor of 0.85 leading from a 400 V, 3 ϕ supply.

Calculate the ~~line current~~ resistance & capacitance of load

$$A) V_{ph} = V_L = 400 \text{ V}; I_L = 18 \text{ A}; \cos \phi = 0.85 \text{ lead}$$

$$I_{ph} = \frac{I_L}{\sqrt{3}} = \frac{18}{\sqrt{3}} = 10.39 \text{ A}$$

$$Z_{ph} = \frac{V_{ph}}{I_{ph}} = \frac{400}{10.39} = 38.5 \Omega$$

(11)

$$R_{ph} = Z_{ph} \cos \phi = 38.5 \times 0.85 = 32.72 \Omega$$

$$X_c' = Z_{ph} \sin \phi = 38.5 \times 0.527 = 20.29 \Omega$$

$$C_{ph} = \frac{1}{2\pi \times 50 \times 20.29} = 156.9 \times 10^{-6} F$$

$$= 156.9 \mu F$$

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Unit - 9

(12)

Transformer (1-P)

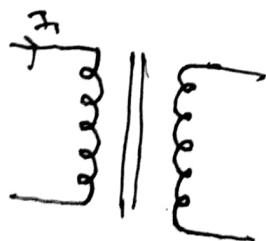
- Transformer works on faradays laws of electromagnetic induction
- Flux change induces current or EMF



- current flow generates flux or magnetic field
- DC current $\rightarrow$ constant flux
- AC current $\rightarrow$ Alternating flux
- Change in flux induces EMF

Dynamically If flux is constant, EMF is zero
Induced $\therefore$
EMF

Transformer has 2 coils placed side by side



- These 2 coils are connected magnetically
- When we pass AC current in one coil, it generates alternating flux

- Change in flux is linked with first coil & second coil & EMFs are generated in 2 coils
- It is statically induced EMF because the components are stationary
- Transformer is a static machine

Definition:- Transformer is a static piece of device used for raising voltage or decreasing voltage of an AC supply with a corresponding decrease or increase in current.

- Iron is used as transformer core or silicon steel
- Air makes the transformer lose flux
- leakage flux:- Flux which is not linking with secondary coil
- Useful flux:- Flux which links with secondary coil
- 95% of flux is useful
- Winding connected to source $\rightarrow$ Primary winding
Winding connected to load $\rightarrow$ Secondary winding
- Generated EMF depends on no of turns of winding
- If $V_2 > V_1 \rightarrow$ step up transformer
 $V_2 < V_1 \rightarrow$ step down transformer

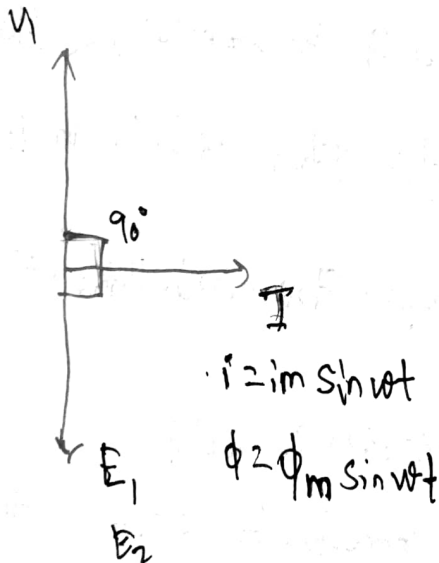
EMF & Flux linkage

$$E_1 = -N_1 \frac{d\phi}{dt}$$

$$E_2 = -N_2 \frac{d\phi}{dt}$$

$$\therefore \frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$$

- minus in the EMF eq shows that ~~direction of~~ ~~current is opposite to flux~~ it is opposite to applied voltage



- Transformer doesn't change frequency
- Two types of losses in transformers:
 - Core losses $\rightarrow$ eddy currents & hysteresis losses
 - Copper losses $\rightarrow$ resistance of winding
- Transformer works only on AC

(113)

Current in transformer = $\frac{V_1 - E_1}{Z_1}$

⑧

• If we apply DC voltage equivalent to AC, then the coil will burn

• Copper loss is also called $I^2 R$ loss

Classification of transformers

Based on phase

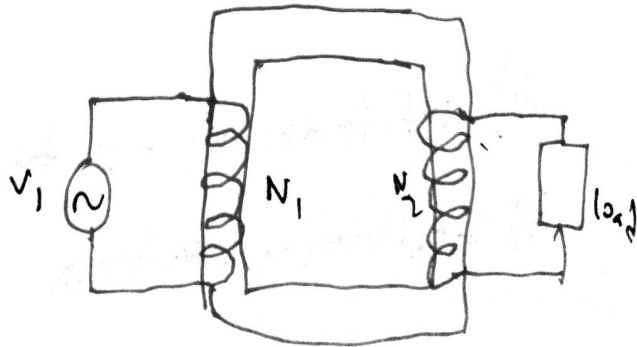
- i) 1-phase
- ii) 3-phase

Based on core

- i) Core type $\rightarrow$ only one flow of path of flux
- ii) Shell type $\rightarrow$ more flows of flux

Ideal transformer

- i) No winding resistance
- ii) No leakage flux
- iii) No iron losses



EMF equation of transformer

$$E_m = 2\pi f N_1 \phi_m$$

rms of primary emf

$$E_1 = \frac{E_m}{\sqrt{2}} = \frac{2\pi f N_1 \phi_m}{\sqrt{2}}$$

$$E_1 = 4.44 f N_1 \phi_m$$

$$E_2 = 4.44 f N_2 \phi_m$$

In an ideal transformer, $E_1 = V_1$ & $E_2 = V_2$

Applications of transformers

- i) Power transformers $\rightarrow$ used in power stations (constant load)
- ii) distribution transformers $\rightarrow$ used for power distribution (variable load)
- iii) Auto transformers $\rightarrow$ Appliances (TV stabiliser)
- iv) Instrumental transformers

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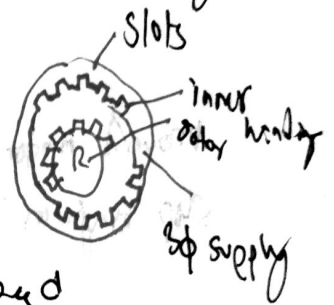
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3- ϕ induction motor

- Used in electric motors
- They run at constant speed irrespective of load
- Their speed is frequency dependent & not easy to control
- DC motors are preferred

- There is a small area b/w stator & rotor so that it freely rotates

- When 3 ϕ supply is connected to 3 ϕ winding a rotating magnetic field develops which rotates around inner periphery $\rightarrow$ synchronous speed



- ^{NSC} rotor is placed on long steel rod called shaft
- For free rotation of rotor & shaft, we use ball bearings
- Slots will be present on rotor & shaft
- We don't give direct current supply to rotor, we use electro magnetic induction to produce current in it.
- In order to reduce relative speed, rotor rotates in same direction of mag field
- All motors work on $P = BIL$ rule

Rotor winding is of 2 types

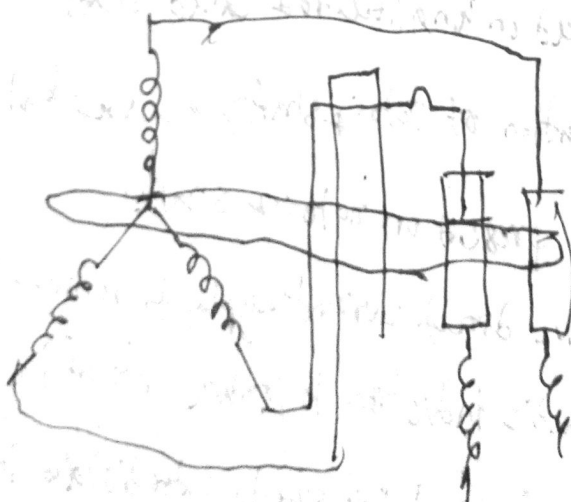
- i) Similar to stator winding $\rightarrow$ wound rotor
- ii) Copper bars

2 ends of copper bars are closed using



Wound rotor is aka slip ring motor because we use slip rings on copper wire

Slip rings & brushes are used to obtain current



Advantages:

1) Simple construction rotor resistance ϕ

2) Cheap to produce and rotor resistance ϕ is high
of low resistance, ϕ is high, ϕ is high, ϕ is high

Disadvantages:

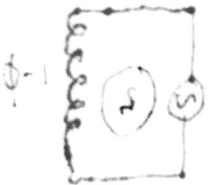
1) Motor also has rotor and also rotor ϕ is high
rotor has rotor and rotor ϕ is high

2) Motor also has rotor and also rotor ϕ is high

3) Motor also has rotor and also rotor ϕ is high



4) Motor also has rotor and also rotor ϕ is high



5) Motor also has rotor and also rotor ϕ is high

6) Motor also has rotor and also rotor ϕ is high

7) Motor also has rotor and also rotor ϕ is high

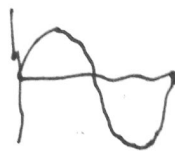
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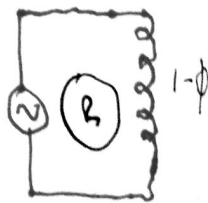
(120)

1- ϕ Induction motor

- Single phase Inductor motor has rating of 1KW
- It is used in fans, refrigerators, washing machines etc.
- Used where current requirement is less
- 1- ϕ motor also has stator and rotor & there is a small air gap between stator and rotor
- Stator $\rightarrow$ stationary
- Rotor $\rightarrow$ rotating
- It produces only alternating magnetic field but it doesn't produce rotation



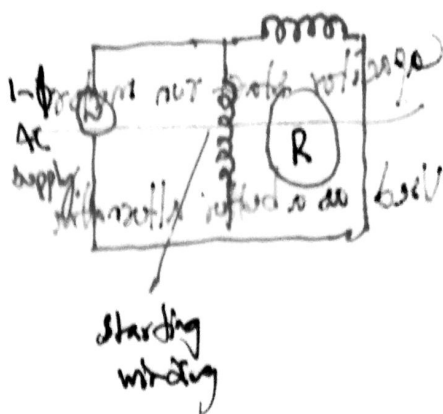
$\downarrow$
Hence 1- ϕ are not self starting motors



- With the help of small modifications, we can turn 1 ϕ motor into self starting
- Rotating magnetic is only produced when there is 2 or more windings with 2 or more phases

split phase induction motor

- Starting winding is only required for starting and needs to be removed once motor rotates
- This can be done by using centrifugal switch



Two

- This type of motor is called split phase induction motor
 - Not suitable for high torque loads
- Capacitor start inductor motor

- It is ~~not~~ too high torque loads
 - we get high torque at high starting time
- 

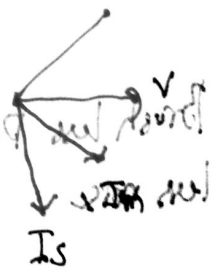


Torque is given by

$$T \propto I_m I_s \sin \phi$$

per selang 16 saat di split phase.

we can increase ϕ by adding a capacitor



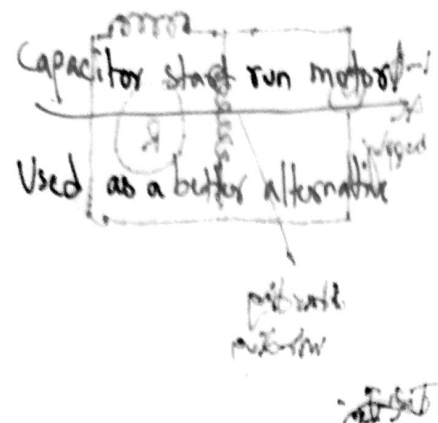
Downback of Capacitor start motor is that if magnetic field is only rotating in the beginning but goes gradually to alternating.

Non uniform field $\rightarrow$ Non uniform force

Non uniform field $\rightarrow$ Non uniform temp.
They produce noise $\rightarrow$ more towards to upper part
force is more for top and bottom

They produce noise
It only produces higher torque in the beginning
but not for long time

rotor not in phase with field

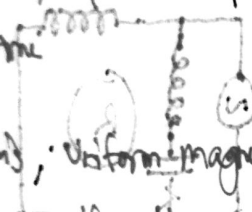


larger phase is present in parallel
and at start line parallel is
rotor not in phase with field
motor not in phase with field
define high field

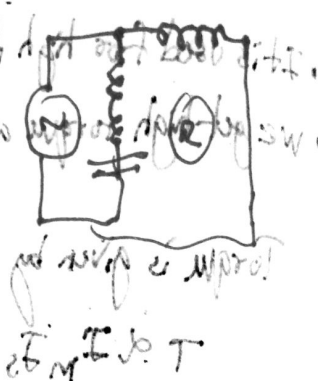
Permanent capacitor

rotor not in phase with field
but it is not in phase with field
about 90 degrees ahead of field
rotor not in phase with field

In this capacitor is present throughout the run time



In this, uniform magnetic field is present
so less uniform torque hence less noise



Brushless DC motor has controllable rotation and makes very less noise

Universal motor

It is a type of motor which can run on both AC and DC supply. It is used in many household appliances like vacuum cleaners, power tools, etc.

Max rpm of AC $\rightarrow 3000 \text{ rpm}$

Max rpm of universal motor $\rightarrow 15000 \text{ rpm}$

It has high rotation speed

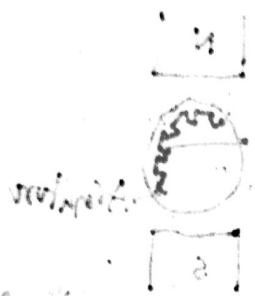
Its speed depends on load

It is a type of motor which can run on both AC and DC supply. It is used in many household appliances like vacuum cleaners, power tools, etc.

It can operate on AC supply or DC supply

DC motor

- requires knowledge of precise location of rotor
- DC motor works on DC supply
- DC motor can operate on AC supply



- To produce work, we need electric supply
- To produce work, we need electric supply
- To produce work, we need electric supply

rotor & stator



- If you have a DC supply
- DC motor can operate on DC supply

rotor & stator

rotor & stator

rotor & stator



rotor & stator

rotor & stator

rotor & stator

rotor & stator

rotor & stator

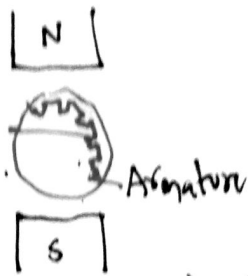
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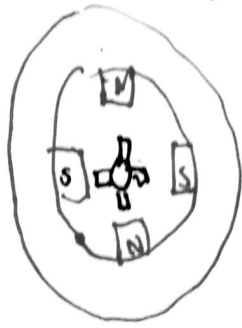
physics of the machine

DC motor

- Motor $\rightarrow$ converts electrical energy to mechanical energy.
- DC motor works on DC power.
- DC motors are superior to AC motors in characteristics
- DC motors are costly
- To produce more torque, we use electro magnets
- Armature helps produce torque
- ~~field~~ field winding is used to produce magnetic poles
- Armature rotates in DC motor



stator $\rightarrow$ field winding
rotor $\rightarrow$ Armature



- It has projecting poles
- DC motor requires power supply for stator & rotor



doubly excited machines

- Induction doesn't work in DC motor
- commutator & brush $\rightarrow$ give power supply to rotating part

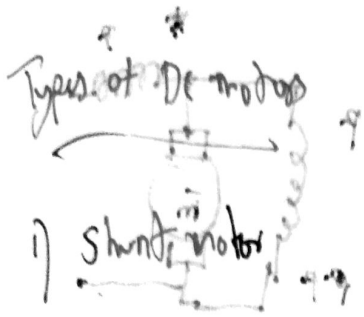
DC machines have:

- i) field system
- ii) armature core
- iii) armature winding
- iv) commutator
- v) Brush



It works on the principle of $F = BIL$

Direction is given by Fleming's left hand rule



1) Shunt motor

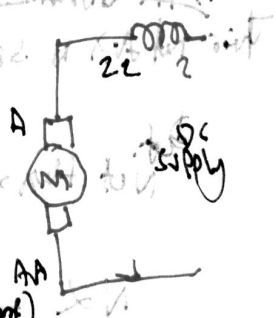
2) Series motor

3) Compound motor

Differential compound
Cumulative compound

Series motor -

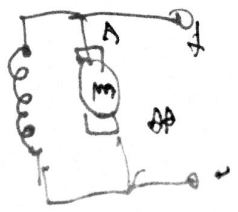
- If field winding is connected in series with armature
- It produces very high starting torque
- Used widely in electric traction, cranes, conveyor belt
- speed of DC motor $\propto \frac{E_b}{\phi}$ (Back emf)



• speed of motor can be controlled using flux control

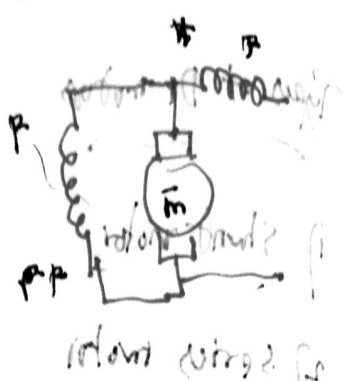
DC shunt motor

- field winding is connected in parallel with armature
- It produces low torque
- It is used for lathe machine, turning machine

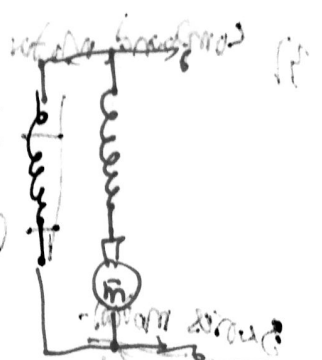


Compound motor (short shunt)

- They have series & parallel motors
- Short field winding is connected only across the armature



It is called long circuit



Differential compound motor is provided with 2 field windings

This motor is used for applications where the speed is to be constant

Not $\Phi_{net} = \Phi_f - \Phi_s$

$N \propto \frac{E_b}{\Phi}$

- It is used for applications where the speed is to be constant
- It works at 50 Hz

It is used for applications where the speed is to be constant



Electrical Earthing

- Process of connecting metallic bodies of electrical equipment to earth by a wire is called earthing
- Wire should have negligible resistance
- It provides protection to the equipment and operator
- It provides for the fault current to flow through it
- We will get electric shock if the current is more than ⁷⁰ ~~10~~ mA

Short circuit

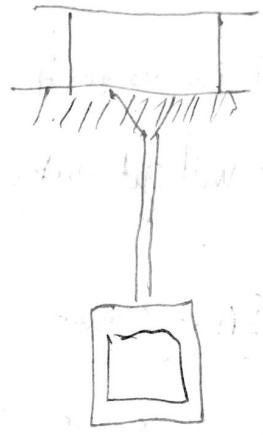
- It occurs when insulation fails and phase wire & live wire have a no resistance path

Types of Earthing

- 1) Plate earthing
 - 2) Pipe earthing
 - 3) Rod earthing
 - 4) Plate earthing
- Earth ~~sys~~ system has earth wire, connector and electrode

Plate earthing

- It consists of GI pipe which carries current from appliance to the copper plate
- Copper has the ~~least~~ least amount of resistance.
- We use Salt or Charcoal to reduce the earth resistance



Pipe Earthing

- This too uses GI pipe
- Surrounding areas of the pipe are covered with salt

Rod Earthing

- In this ~~rod~~ Copper rod is directly inserted into ground
- It is used for lightning strokes

Strip Earthing

• It is used in substations

• we use earth pipe (copper) here

• we also use it in places where there are more rocks



Advantages

• Safety for human & appliance

• voltage stabilization

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Basic concepts of lighting sources

- Basic bulb is incandescent bulb or filament lamp
- Carbon filament bulb $\rightarrow$ first bulb by Joseph Wilson Swan
- Carbon was replaced by tungsten because of its properties
- Then it turned into coiled filament came out
- Principle behind incandescent lamp is incandescence

Incandescence:- When a hot body is heated, radiant energy is emitted in wave form

- It generates light through heat and has 5% efficiency
- It is filled with vacuum or inert gases

Applications:- Domestic, Commercial & Industrial

- Carbon filament lamp was used in cinema projectors

Properties of filament

- High ΔL_m
- High melting point
- Low temperature coefficient

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low vapor pressure

Mechanically strong, ductile

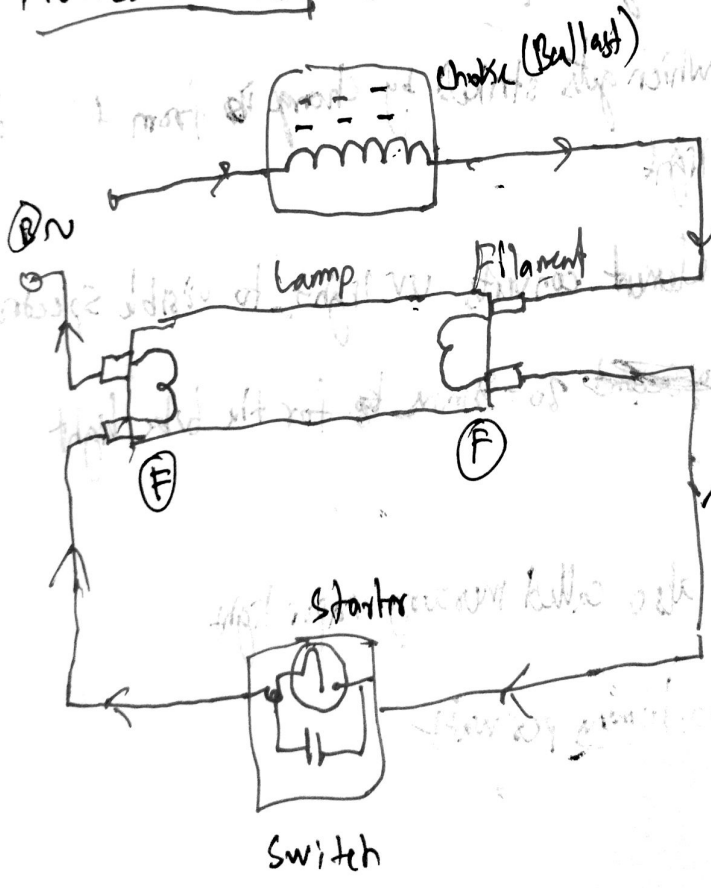
Material $\rightarrow$ Carbon, Tungsten, Osmium, tantalum

Gas $\rightarrow$ Nitrogen or Argon

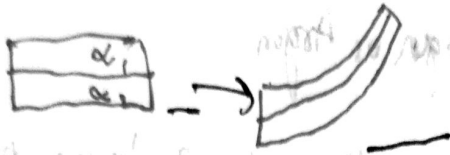
Life $\rightarrow$ 1000 hours working, 40-30 lumens per Watt

We use LED instead of incandescent bulb

Fluorescent Lamp



- Starter has bimetallic state with different coefficient of expansion
- It becomes curved when heated and opens the circuit

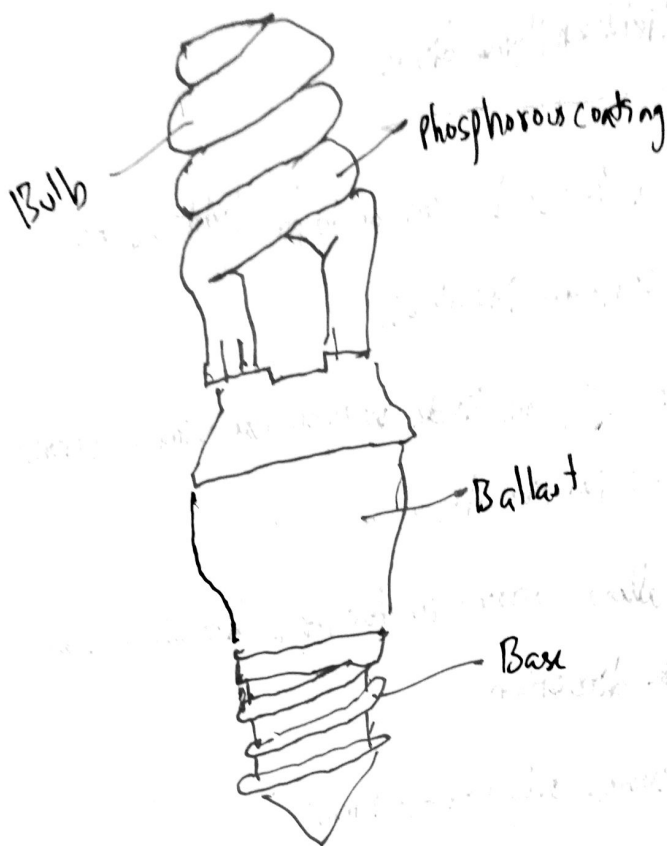


- Ballast is an inductor which doesn't allow sudden change in current
- High voltage ionizes vapour inside tube
- The particles which get struck by charge from filament produce UV light
- Phosphorous element converts UV light to visible spectrum
- It takes ~~3-30 seconds~~ 20-30 mins for the tube light to glow
- Tube light is also called mercury vapor light
- Gives 50-100 lumens per watt

Drawbacks
 Drawback of ~~fluor~~ fluorescent lamp is the starting time
 , size is huge

CFL (Compact fluorescent lamp):

It is the miniature version of fluorescent lamp



- It can fit in bulb holder
- It is a screw type bulb
- It used electrical ballast it produces high voltage at starting
- Electronic ballast reduces I^2R loss. It is also connected to a Capacitor

Life span $\rightarrow$ 6000 - 15000 hrs

Energy consumption $\rightarrow$ less

Cost $\rightarrow$ more

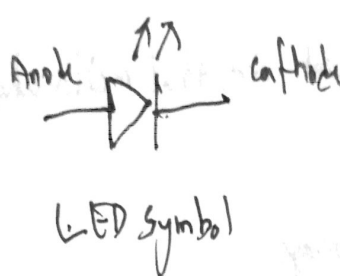
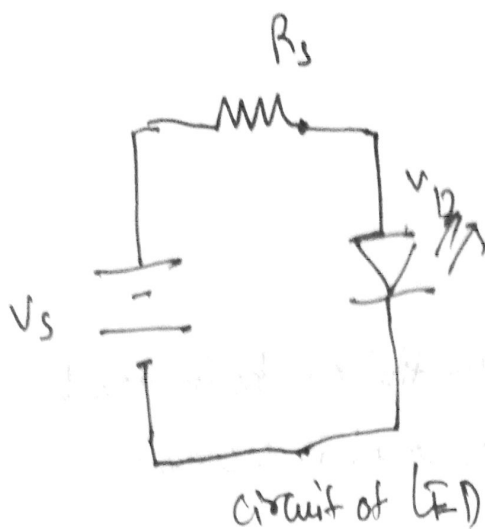
LED (light emitting diode)

- It is a 2 lead semiconductor light source
- GE company invented it
- It is a special diode which has similar characteristics to a PN junction diode
- LED allows current in forward direction & blocks reverse direction
- It occupies only area of 1 mm^2
- Invented in 1962

life span $\rightarrow$ 50,000 - 100,000 hours

Energy consumption $\rightarrow$ low

Cost $\rightarrow$ cheap



Applications

1) Signs & signals

2) Displays

3) Exit signs

4) Flash lights

5) Under counters

Drawback

- It is not suitable for heating
- It also causes skin diseases

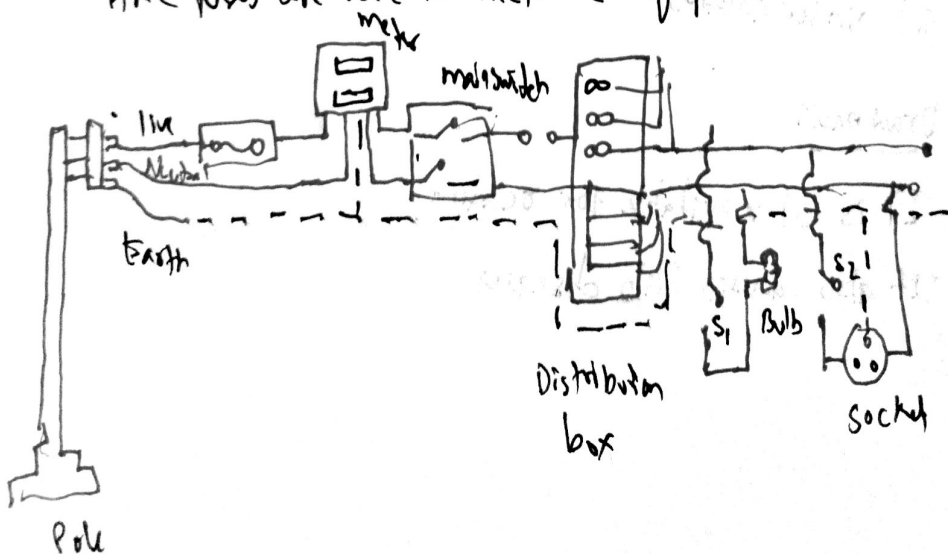
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Fuse

- Fuse is a safety device that operates to provide protection against the overflow of current in a circuit
- It is an over current protection device
- Main component is a metal wire that melts when too much current flows
- It avoids further damage

Purpose:-

- To protect components from over currents
- To isolate sub systems from main system once fault occurs
- Older fuses are called Kit Kat fuse or rewirable fuse
- HRC fuses are used in electronic equipment



Characteristics of fuse elements

- low melting point
- High conductivity
- Free from oxidation
- Low cost

Lead & tin are preferable

Types of fuses

- Low voltage fuse
- High voltage fuse

Re-wirable fuses disadvantages

- Delay in operation
- Risk of fire
- Unreliable operation
- Lack of discrimination

Blade type fuses

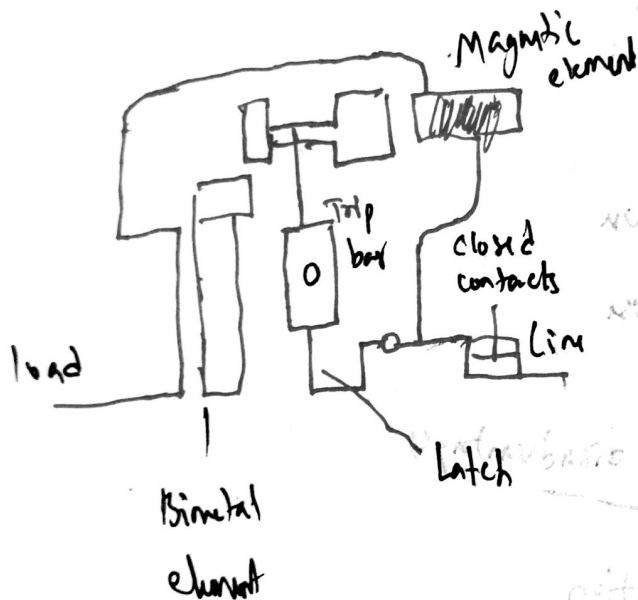
- Used in automobiles

Drawback of fuse

- Needs to be replaced after operation

Miniature circuit breaker (MCB)

- It is an automatically operated electrical switch
- It prevents damage to circuit in case of over current
- They trip during overload
- They can differentiate b/w normal current, excess current, short circuit current



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Electrical batteries

- Battery is a source of EMF in which chemical energy into electrical energy

- Cell contains 2 plates dipped in suitable solution

- plates $\rightarrow$ electrodes

- Solution $\rightarrow$ electrolyte

- Magnitude of emf of a cell depends upon

- (i) nature of material

Types of cells

1) Primary cells

- Chemical reaction is not reversible

Eg:- dry cell, Alkaline cell

- It stops working when active materials are nearly consumed

- It cannot provide large & steady current for a longer period

Alkaline battery

- Use electrolyte of alkali

Zinc carbon battery

- Most popular & cheap

Secondary cells

- Cell in which chemical reaction can be reversed
- There is no actual consumption of any plate
- When discharging, chemical action changes composition of plates
- Can be recharged

eg:- Lead-acid, Nickel-cadmium alkaline, Li-Po